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REVIEW ARTICLE

Estimating aboveground woody biomass of forests in Poland for FAO/ECE and UNFCCC reporting

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Abstract. The United Nations Framework Convention on Climate Change and the Kyoto Protocol have committed member states to reduce greenhouse gas emissions by, among others, promoting the increase of carbon sequestration by carbon sinks (including woody biomass in forests). In order to achieve these objectives, an international reporting system was designed.

The stock of woody biomass depends on several environmental and managerial factors, which determine species composition and age structure of a forest as well as characteristics of individual trees. Estimating aboveground woody biomass, especially on a nation-wide level, is generally based on the application of conversion factors to known characteristics such as the volume of the growing stock. The application of default conversion factors, as proposed by international guidelines, however, is questionable, since inventory systems for and definitions of growing stock differ from country to country.

In this paper, the methods used in Poland to estimate woody biomass for the FAO and the UNFCC reporting, were presented and analysed. We also analysed the influence of some stand and tree characteristics, such as tree species composition and content of bark and its density, on the stock of woody biomass. We conclude that issues not addressed in the IPCC guidelines, such as big differences in wood and bark density, especially for pine, need to be taken into consideration when making estimations. Moreover, the results of this paper show that biomass conversion and expansion factors (BCEF) proposed by IPCC are not adequate for Polish conditions.

Key words: woody biomass, wood and bark density, BEF, BCEF, IPCC guidelines, carbon sequestration

1. Introduction

From 1946, the Food and Agriculture Organization of the United States (FAO) together with United Nations Economic Commission for Europe (UNECE) are conducting evaluation of World's forest. Shortly after World War II, problem of stock availability was a basic field of public opinion's interest. As a response to perception change of role and meaning of forests (Bengtsson et al. 2000; Farrell et al. 2000), the range of information topics collected by FAO gradually expanded (FAO 2010).

Concerns about state of natural environment, in particular influence of greenhouse gas concentrations in the atmosphere at the Earth's climate, led to the adoption in 1992 The United Nations Framework Convention on Climate Change (UNFCCC). In executive document to the Convention, i.e. Kyoto Protocol (1998), parties to the UNFCCC have committed to reduce the overall emission of six greenhouse gases and have established main rules to achieve this goal.

The ways to reduce emissions, besides industrial emissions reduction, are actions favouring carbon sequestration through direct human-induced land-use change and forestry activities (LULUCF) (Michalak, Jabłoński 2007).

Reporting on anthropogenic greenhouse gas emissions and removals resulting from activities under

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article 3.3 of Kyoto Protocol (afforestation and deforestation) and 3.4 (inter alia forest management) in a first commitment period (2008–2012) should be held with the use of good practice guidance developed in 2003 by Intergovernmental Panel on Climate Change (Decision 17/CMP.1 2006). IPCC guidance (Penman et al. 2003) determines among others ways of designing key categories of carbon pools required for reporting within six main categories of land use. Moreover, include main reporting assumptions and default factors for use in case of lack of detailed models and national factors.

Data concerning the size of wood biomass and carbon stock in forests at national and global level are published among others in UNECE and FAO reports (UNECE/FAO 2000, FAO 2006, FAO 2010). Carbon stock is also one of the indicators of sustainable forest management monitored within Forest Europe process (previously Ministerial Conference on the Protection of Forests in Europe) (MCPFE/UNECE/FAO 2003; MCPFE/UNECE/FAO 2007; Forest Europe/UNECE/FAO 2011). Preparing the data concerning the size of wood biomass in Poland for mentioned reports was the task of Forest Research Institute.

The aim of the following article is a presentation of methods used in Poland for assessing the stock of aboveground woody biomass in forests in the context of international reporting needs, with special attention to applicability of default factors proposed by IPCC. The analysis of existing methods, availability of data and research conducted in the last years will allow, moreover, to indicate directions of future actions – research necessary for improving reporting process.

2. General assumptions for estimation of woody biomass

Estimation of woody biomass in forests in dependence on the type of initial data may be conducted with one of two methods (Somogyi et al. 2007; Zasada et al. 2008). The first one uses functional relations between biomass size and tree's parameters such as diameter at breast height (dbh) or height. In case of having already aggregated inventory data (for instance, stem or merchantable tree volume) conversion ratios are useful. Such factors allow estimation of biomass that does not undergo inventory procedures (Brown et al. 1999) and conversion of volume (expressed in cubic meters) to tonnes of dry mass.

The issue of wood biomass estimation, especially in recent decades, was a subject of many scientific research. For instance, in Zianis et al. (2005) thesis, over 600 empirical formulas for estimating whole trees biomass or their individual components were listed. Quoted authors (Zianis et al. 2005) specify 17 equations from Poland, which in majority come from Oleksyn et al. (1999) thesis and regard 12-year-old pine cultivations of different provenances. Mukkonen et al. (2006) in addition to earlier elaboration (Zianis et al. 2005) list additional 188 algorithms for estimating biomass of European tree species, whereof two equations regard estimating biomass of pine's needles in Poland. Existence of high dependence between stock of biomass and such variables like tree species, tree age, habitat conditions or a methods of forest management (Zianis et al. 2005) results in the necessity of paying special attention while estimating wood biomass on regional or national level. Moreover, Somogyi et al. (2007) emphasize the problem of definitional divergence and possibility of using biomass equations developed on the basis of sparse empirical material. In specific conditions, a parameter strongest correlated with tree's biomass is for instance dbh, whereas tree's height and crown dimensions have smaller meaning (Cienciala et al. 2008). However, in other case tree's height is indicated as a parameter the most correlated with biomass, especially in large-area context (Fang et al. 2006).

Due to complexity of this issue, empirical studies conducted so far in Poland did not have a comprehensive character. Research regarding relations between pine's linear dimensions (dbh and height) and its aboveground biomass conducted recently inter alia (Socha and Wężyk, 2004; Zasada et al. 2008). Quoted authors in separate thesis placed results regarding needles biomass (Socha and Wężyk 2007; Bronisz et al. 2009). Building equations for pine's needles biomass was also a subject of Jelonek et al. (2011) research. Pietrzykowski and Socha (2011) analysed the size of pine's biomass on reclaimed habitats. Jagodziński and Kałucka (2011) and Bijak et al. (2013) were estimating the belowground biomass of birch and pine in stands resulting from afforestation on agricultural lands. Worth noting are also Orzeł et al. (2005, 2006a, 2006b) thesis. Mentioned authors with the use of empirical equations developed by other scientists (including foreign) attempted estimating the total aboveground biomass of stands (all layers of trees and shrubs).

In case of reports prepared so far by Poland for FAO and UNFCCC, initial information available in national statistics was merchantable volume of growing stock according to age classes and dominant tree species. Aboveground biomass was estimated using some default factors.

Estimation of total aboveground biomass may be conducted with the use of two factors (expansion and density), or one that allows direct conversion of (merchantable) growing stock volume to dry mass (Lehtonen et al. 2004). In IPCC, guidance (Penman et al. 2003) was introduced to two separate sets of factors for the calculation of biomass stock, i.e. biomass expansion factors (BEFs) and basing wood density factors (D). Expansion factor is a ratio of the total aboveground volume of growing stock to volume of merchantable components of growing stock (which undergoes inventory). In developed in 2006, further IPCC guidelines (Eggleston et al. 2006) for estimating aboveground biomass on the base of merchantable volume of growing stock were proposed a set of indicators called BCEF (biomass conversion and expansion factors). As emphasised by Eggleston et al. (2006), from methodological point of view, BCEF indicators correspond to products of basing wood density factors (D) and expansion factor (BEF). In many scientific studies (for instance, Brown et al. 1997; Brown and Schroeder 1999; Lehtonen et al. 2004; Wojtan et. al. 2011), factors for direct conversion of merchantable or stem volume to total tree biomass are described as BEF. In the following thesis, due to references to IPCC guidelines (Penman et al. 2003; Eggleston et al. 2006) occurring in FAO guidelines (2004a, 2008), a way of defining factors from IPCC guidelines was adopted. Moreover, it seems that separation of two processes, i.e. estimation of total wood stock and its conversion into tons of dry mass, will facilitate evaluation of particular factors.

3. Methods of aboveground biomass estimation for Poland

3.1. UNECE/FAO forest resources assessment TBFRA-2000

According to UNECE/FAO wood biomass definition, biomass of woody parts of trees (wood, bark, branches, stumps, roots, excluding the leaves) measured from 0 cm dbh (UNECE/FAO 2000) should be reported to the Temperate and Boreal Forest Resources Assessment (TBFRA-2000). Biomass defined in this way was the derivative of volume of growing stock, which according to UNECE/FAO definition included woody parts of trees also measured from 0 cm dbh, including tops of stems and thicker branches.

Estimation of volume of growing stock in Poland for TBFRA-2000 required supplementing values already available in Polish statistics (merchantable volume of growing stock) by volume of branches, stem tops and trees not included in inventory procedures, i.e. of diameter or dbh below 7-cm overbark. For this purpose, growth and yield tables collated by Szymkiewicz (1971) were used. On the basis of tree species, age and site index of stands managed by National Forest Holding 'State Forests' mean site index of individual species by age classes was calculated. Next step was the estimation of expansion factors for the given species, age class and site index, i.e. a ratio of total growing stock per hectare and merchantable volume of growing stock according to Szymkiewicz (1971) tables. In case of youngest stands (to 20 years) not included in yield tables, information about growing stock per hectare was adopted on the basis of Łonkiewicz (1992) studies. Expansion factors (BEF) defined with the use of Szymkiewicz (1971) tables in case of pine ranged from 1.67 for stands in age 21–40 to 1.10 for stands over 140 years old. Generalised factor for coniferous species was 1.265 and for deciduous species 1.170. With the use of mentioned factors, the total volume of growing stock in Poland was calculated based on the volume of merchantable components of growing stock published by Main Statistical Office.

It should be noticed that tables collated by Szymkiewicz (1971) do not include volume of trees and shrubs of undergrowth layers. Assessment of volume of those layers within TBFRA-2000 was not possible.

The stock of tree biomass for TBFRA-2000 was defined as a product of total growing stock and density factors applied in UNECE/FAO assessment for year 1990 (Łonkiewicz 1992). For coniferous species, density factor was 0.4 and for deciduous trees 0.57. Those factors were related to volume overbark and took into account different densities of wood and bark. Issue of wood and bark density factors variability will be the subject of analysis in further part of thesis.

3.2. FAO forest resources assessment – FRA 2005

Starting point for biomass estimation for FRA 2005 like in earlier FAO assessment was volume of growing stock. It should be noticed, however, that in case of FRA 2005, definition of growing stock was changed compared with TBFRA-2000 guidelines. Each country had a possibility to report the volume of growing stock by declaring themselves minimum trees diameter on breast height and in thinner end of trees (FAO 2004b). In case of Poland, 7-cm overbark was adopted as a threshold for dbh and top diameter, value used in practice for merchantable timber (Michalak et al. 2005).

FAO guidelines (2004a) for country reporting to FRA 2005 recommended determining first of all wood biomass with the use of national expansion and density factors. When there were no national indicators, regional factors could be used. Finally, if above was not possible, default factors proposed by IPCC (Penman et al. 2003) should be used.

For estimation, the stock of woody biomass for Poland default BEF and basing wood density factors from IPCC guidance were used. Proposed in IPCC guidance (Penman et al. 2003), BEF for coniferous species of temperate zone amounted 1.3, and for deciduous species 1.4. The wood density factors for chosen tree genus from IPCC guidance are shown in Table 1.

Adoption of default factors for biomass assessment results from two reasons. First, national expansion factors defined for TBFRA-2000 became irrelevant because of change of age and species structure of forests in Poland. Additionally, it was not possible to assure adequate data quality because of lack of data on country level about merchantable volume of growing stock. Necessary parameters were estimated by experts.

3.3. FAO forest resources assessment – FRA 2010

In case of FRA 2010, definition of growing stock from previous assessment (FAO 2007) was kept. In Polish report to FRA 2010 merchantable volume of growing stock was reported. Guidelines prepared by FAO (2008) indicated the possibility of using two sets of default factors proposed by IPCC for the estimation of aboveground biomass. It was possible to use BEF and basing wood density factors (like in FRA 2005) or BCEF factors. As an effect of arrangements made with UNECE, i.e. unit responsible for verification of national report for Europe region, BCEF factors were adopted for the estimation of aboveground biomass in Poland. The values of BCEF proposed by IPCC varied depending on climate zone, trees species (or forest type) and average growing stock per ha. Average values of BCEF indicators for forests of temperate zone (Eggleston et al. 2006) are shown in Table 2. Choice of factors for Poland was made on the basis of average growing stock, which is over 200 m^3/ha. Keeping consistency with data reported for earlier reporting years (1990, 2000, 2005) requires their recalculation with the use of new factors. Methodological solution adopted for FRA 2010 was used also for reporting about carbon stock within Forest Europe process (Forest Europe/UNECE/FAO 2011).

Table 1. Basic wood densities [grams dry matter/cm^3 fresh volume]

Tree genus	IPCC Guidance (Penman et al. 2003)	Poland's National Inventory Report (KOBiZE 2013)
Pine	0.42	0.43
Spruce	0.40	0.38
Fir	0.40	0.36
Beech	0.58	0.57
Oak	0.58	0.57
Hornbeam	0.63	0.63
Birch	0.51	0.52
Alder	0.45	0.43
Populus	0.35	0.35
Aspen	0.35	0.36

3.4. Reporting under UNFCCC and Kyoto Protocol

Within UNFCCC and Kyoto Protocol, emissions and removals of carbon dioxide inter alia from forest land are reported. Estimation of stock and changes of woody biomass is an intermediate stage of this reporting. Unit responsible for preparing submissions about emission and removals of carbon dioxide from forests in Poland is National Centre for Emission Management (KOBiZE) at the Institute of Environmental Protection.

The information included in recent submission to UNFCCC (KOBIZE 2013) results suggest that the estimation of changes of aboveground biomass stock was consistent with IPCC guidance (Penman et al. 2003). Wood density factors used by KOBiZE (2013) are shown in Table 1. Those factors were used by KOBiZE (2013) for the estimation of average wood density indicator, which amounted to 0.446 g/cm^3. Calculation was based on information about growing stock by dominant species in State Forests (BULiGL 2012). Indicators regarding increment of merchantable volume of growing stock in State Forests were increased by the usage of BEF factors from IPCC guidance (Penman et al. 2003) amounting to 1.3 and 1.4, respectively, for coniferous and deciduous species (KOBiZE 2013).

Table 2. Default BCEF factors (average values) for expansion merchantable growing stock volume to aboveground biomass for temperate forests (after IPCC Guidelines 2006)

Forest type	Growing stock [m³/ha]				
	≤20	21–40	41–100	101–200	>200
Broad-leaved	3.0	1.7	1.4	1.05	0.8
Pine	1.8	1.0	0.75	0.7	0.7
Other coniferous	3.0	1.4	1.0	0.75	0.7

4. The analysis of applied factors and methodological rules

4.1. Wood density factors

Wood density depends on many parameters out of which to the most important are tree species and wood humidity (Krzysik 1974). Important are also age of tree and environment factors (Spława-Neyman 1994), the percentage of late wood (Tomczak, Jelonek 2012) and management treatments (Spława-Neyman et al. 1995). Equally important is geographical location. Wood density of the same species is different in individual regions of Poland (Witkowska, Lachowicz 2013).

Wood density, i.e. mass to volume ratio (expressed in g/cm³ or kg/m³), takes into account wood porosity and water included in wood (Krzysik 1974). With the increase of wood density, its humidity drops (Giefing, Jabłoński 1989; Hylińska- Raczkowska 1996).

In case of chemical wood processing, when material efficiency does not decide volume but amount of wood substance, basing density defined as tonnes of oven-dry wood per cubic metres of green volume (in stage of maximum swelling of wood) is applied (Krzysik 1974). State of maximum swelling of wood can be equated with the volume of trees growing in forest or a state right after tree felling (Witkowska, Lachowicz 2013). Basing wood density factors are used for estimating the stock of woody biomass in forests.

In recent national submission under UNFCCC (KOBiZE 2013), another approach was applied. Basic wood density was calculated using specific gravity (oven-dry mass per oven-dry volume) and volumetric shrinkage for particular genus of trees. Estimation of woody biomass basing only on specific gravity will lead to overestimation of biomass in forests. Although KOBIZE report does not contain unequivocal records, the factor values and literature list suggest that their most probable source is Krzysik (1974) publication.

Basing wood density listed in KOBiZE (2013) report differ insignificantly from factors proposed in IPCC guidance for the species of boreal and temperate forests (Penman 2003; Table 1). The source of factors proposed by IPCC is Dietz's thesis (1975). Despite the Krzysik (1974) does not precise the source of factors listed in his elaboration, identical values of specific gravity were published by Kollmann in 1951 (after Trendelenburg, Mayer-Wegelin 1955).

Differences between factors used in Polish submission under UNFCC and those listed in IPCC guidance are small. Average basic density (for all species) estimated on the basis of factors from IPCC guidance is almost identical with the one used in Polish submission (0.446 g/cm³) and amounts to 0.444 g/cm³. In case of individual species, differences of density at 0.01 g/cm³ level may indicate from rounding basic density factors to two decimal places.

Basic wood density factors used for estimating biomass stock on national level should correspond to average values of it for a given species. Similar to the BEF, determination of average values of basing wood density even for one species on country level, due to its large variability, is a big challenge. It is well illustrated inter alia in Witkowska and Lachowicz's (2013) research. According to those results, basic wood density of pine's stem is 0.417 g/cm³, which is almost identical with factor obtained by Dietz (1975). However, Witkowska and Lachowicz (2013) stated, basing wood density of pine's stem growing on fresh coniferous forest habitats is on average 0.419 g/cm³, on fresh mixed coniferous forest habitats – 0.415 g/cm³, and on fresh mixed broadleaved forest habitats – 0.409 g/cm³. Average basing wood densities are an effect of research material comes from four locations in Poland. Average basing wood density on fresh mixed coniferous forest habitats in the southwest part of Poland was 0.432 g/cm³, in north part of Poland 0.411 g/cm³ and in north-east only 0.402 g/cm³. Determination of average basic wood density for country would require, therefore, determination of weighed average, resulting at least from growing stock volume of given species according to forest habitat types, geographical location and age structure. Although Witkowska and Lachowicz's (2013) research are conducted on 400 sample trees, it did not include, however, full range of tree age classes.

Observed, especially with pine, decreasing of wood density from stump to tree's top (Trendelenburg, Mayer-Wegelin 1955; Pazdrowski 1992; Pikk and Kask

2004; Witkowska and Lachowicz 2012) requires also appropriate approach in calculations. Wood density should be defined on the basis of measurements performed on different heights of trees and with usage of weighed average of individual sections (Helińska-Raczkowska and Fabisiak 1992). Cited values of basic wood density from Witkowska and Lachowicz's (2013) research come from measurements on three heights on stem but they are arithmetic means.

Wood density depends also on tree's biosocial position, and those relations may additionally change with age (Pazdrowski and Spława-Neyman 1993). From quoted authors research indicate, that in case of pine, predominant and dominant trees are characterised with higher wood density in comparison to dominated trees. Pazdrowski and Spława-Neyman (1993) analysed, however, specific gravity in dry state, not basic wood density and only on dbh. The largest basic wood density of predominant trees (in over 100 years old pines stands) stated also Jelonek et al. (2009), but only on post-agricultural lands. In case of areas covered with forest for at least three generations those authors (Jelonek et al. 2009) observed that trees passing to lower biosocial classes are characterised with higher density. Also, Helińska-Raczkowska and Fabisiak (1992) stated that trees of fast growth (so-called wolf trees) are characterised with low average density. For 23 years old pines, they obtained basic wood density in range of 0.321–0.360 g/cm^3.

In the context of wood biomass change estimation for submissions under UNFCCC and Kyoto Protocol, worth noting are research conducted by Tomczak and Jelonek (2013) in 88–102 years old pine's stands. Analysis conducted on definitely bigger empirical material than in earlier thesis (Jelonek et al. 2009) indicates that in case of pine from post-agricultural land habitats wood on dbh is characterised with relevantly lower basic wood density (0.435 g/cm^3) than in case of trees on forest areas for at least several generations (0.478 g/cm^3). It is inter alia an effect of faster growth in thickness of pines on post-agricultural land (Tomczak et al. 2009). Through analogy to Spława-Neyman et al. (1995) research can be expected that forest stands resulting from natural expan-sion, with lower density of trees than in artificial forest regeneration, will be characterised with larger percent-age of juvenile wood what results therefore in lower wood density (Tomczak and Jelonek 2012).

Precise estimating of woody biomass on country level requires including differences of basic wood density within particular species and between them (Table 1). When average basic wood density for all species is determined together, just like it is being done in submission prepared by Poland under UNFCCC (KOBiZE 2013), wood density factor would depend on the share of particular species in growing stock volume. KOBiZE (2013) for determining average wood density used a structure of growing stock by dominant species in State Forests (Table 3) (BULiGL 2012). Results of National Forest Inventory (NFI) showed that the structure of growing stock by tree species in Poland differs from data aggregated by dominant species in State Forests (BULiGL 2013). First of all, lower (by over 10%) share of pine (Table 3) should be noticed. Higher share of oak in NFI is mainly an effect of distinguish trees growing in lower stands layers. Average basic wood density estimated with NFI data (BULiGL 2013) is 0.455 g/cm^3. A difference between above factor and used in Polish submission under UNFCCC (0.446 g/cm^3) results in 2% difference of woody biomass stock.

4.2. Bark percentage and density

Bark percentage, in dependence on tree species and its age, may range from few to over 20% of the total volume of tree overbark. Due to small economic meaning of bark, treated in the past as industrial waste (Krzysik 1974), its physical properties especially in Poland were a subject of research in much smaller range than wood properties. Basic bark density factors of chosen tree species determined by Dietz (1975) are shown in Table 4. Because bark density is lower than wood density, calculation of woody biomass should be conducted separately for bark and wood, especially for main species in Poland like pine, oak and spruce. This approach was used for the estimation of averaged density factors and biomass stock in Poland for TBFRA-2000.

To determine the level of removals underbark within forest management planning in State Forests, reduction indicator in reference to volume overbark which amounts to 0.8 is adopted (Instrukcja 2012). Adoption of 20% of bark is a major simplification, depending on averaging bark percentage of individual species and age classes.

Average basic density factors of growing stock in Poland, defined on the basis of wood and bark basic density factors from Dietz (1975) research and assuming 20% bark percentage, estimates 0.437 g/cm^3 (Table 5). The stock of woody biomass taking into account lower bark density is smaller by 4% towards value determined only on the basis of wood density factors.

If we use bark percentage for individual species, more precise results may be expected. A species with the smallest bark percentage in Poland is beech. The

Table 3. Species composition of forests in Poland

Tree genus	Merchantable volume of growing stock by dominant species in State Forests' stands (BULiGL 2012)		Merchantable volume of growing stock by species in Poland (BULiGL 2013)	
	1×10^6 m^3	%	1×10^6 m^3	%
Pine	1250.8	69.7	1407.2 1)	58.5
Spruce	104.9	5.8	168.8	7.0
Fir	51.9	2.9	89.5	3.7
Beech	105.7	5.9	165.2	6.9
Oak	123.5	6.9	256.8 2)	10.7
Hornbeam	4.7	0.3	29.1	1.2
Birch	75.3	4.2	149.3	6.2
Alder	71.1	4.0	112.5	4.7
Populus	1.4	0.1	3.3	0.1
Aspen	4.1	0.2	23.1	1.0

1) and other coniferous species not listed in the Table
2) and other broad-leaved species

research conducted by Dudzińska (2004) indicates that the percentage of beech bark in overbark stem volume in Karpaty mountains (in stands aged 30–130) ranges from 4% in oldest stands to 15% in the youngest and on average it is 7%. Smaller percentage of beech bark does not influence the accuracy of biomass calculation because this species according to Dietz (1975) is characterised with identical wood and bark basic density. Species with of large differences in of wood and bark density are pine and oak. According to Bruchwald (1998), average percentage of oak bark is around 19% so it is close to general indicator used in State Forest. Using empirical formulas developed by Rymer-Dudzińska (1997) for calculating percentage of pine bark, we obtain smaller bark percentage than the one adopted in forest management planning. In stands of 10-m height, percentage of bark in total pine volume is 19%; however, in stands of heights 20 and 30 m – 15% and 12%, respectively.

Inclusion of the bark in woody biomass estimation causes decrease of biomass stock in comparison with the results of estimation based only on wood density factors. The differences may range from 3% to 4% with 15% and 20% bark percentage, respectively (Table 5).

4.3. Biomass expansion factors (BEF)

Biomass expansion factors for coniferous species adopted for TBFRA-2000 amounting to 1.265 was almost identical with the indicator proposed by Trampler (1982) for this group of species (1.264). Convergence of factors points to a similar procedure pattern, i.e. usage of growth and yield (Szymkiewicz 1971) for estimation of non-merchantable components of growing stock (branches tops and whole trees of thickness below 7 cm). For deciduous species, Trampler (1982) adopted 1.208 biomass expansion factor, which is higher than indicator defined only with the use of growth and yield tables during TBFRA-2000 evaluation equals 1.170.

Table 4. The basic bark density (after Dietz 1975)

Tree genus	The bark density
	g/cm^3
Pine	0.30
Spruce	0.34
Fir	0.46
Beech	0.58
Oak	0.42
Hornbeam	0.53
Birch	0.56
Alder	0.43
Populus	0.41
Aspen	0.43

Table 5. Woody biomass and average density of merchantable components of growing stock volume (≥7 cm over bark) of forests in Poland

Tree genus	Merchantable volume of growing stock in Poland (BULiGL 2013)	Woody biomass based on the basic wood density (Dietz 1975)	Woody biomass based on the basic density of wood and bark (Dietz 1975)	
			bark percentage – 20%	bark percentage – 15%
	1×10^6 m^3	1×10^6 t	1×10^6 t	1×10^6 t
Pine	1407.2	591.0	557.3	565.7
Spruce	168.8	67.5	65.5	66.0
Fir	89.5	35.8	36.9	36.6
Beech	165.2	95.8	95.8	95.8
Oak	256.8	149.0	140.7	142.8
Hornbeam	29.1	18.4	17.8	17.9
Birch	149.3	76.1	77.6	77.2
Alder	112.5	50.6	50.2	50.3
Populus	3.3	1.2	1.2	1.2
Aspen	23.1	8.3	8.6	8.6
TOTAL	2405.0	1093.8	1051.6	1062.2
average density factors [g/cm^3]		0.455	0.437	0.442

Expansion indicators adopted for TBFRA-2000 does not include biomass of needles and leaves, included in IPCC default factors (Penman et al. 2003). Orzeł et al. (2006a) defined share of needles in pines stands located in south Poland on 3.2% of total aboveground biomass. The estimation conducted by Orzeł et al. (2006a) indicates additionally that the share of shrub layer in the total biomass of analysed pine stands was 1.3%. According to Wojtan et al. (2011), the share of pine's branches with needles is almost 5%. Biomass expansion factor adopted for coniferous species in TBFRA-2000 after needles biomass consideration (and alternatively shrub layers) would be similar to IPCC default factor amounting to 1.3.

Bigger differences occur between expansion factors for deciduous species. IPCC default factor amounts to 1.4, while indicator assessed on the basis of Szymkiewicz (1971) growth and yield tables for TBFRA-2000 equals only 1.17. The research conducted by Orzeł et al. (2005, 2006b) in alder and oak stands indicates that the biomass of leaves constituted less than 2% of the total aboveground woody biomass. Those authors assessed also share shrub layer in total growing stock volume for about 1% and slightly over 2%, respectively, in oak and alder stands (Orzeł et al. 2005, 2006b).

Conduction of unambiguous verification of BEF used in international reporting on the base of research concerning the stock and allocation of woody biomass in Polish forests is not possible, however. For example, Socha and Wężyk (2004) and Zasada et al. (2008) research was focused on empirical equations for single trees biomass estimation (on the basis of their dbh and height), not for expansion factors including inter alia undergrowth layers of forest stands. Although on the basis of Orzeł et al. (2005, 2006a, 2006b), research is possible to elaborate BEF, however, in relation to stem of trees, not merchantable volume of growing stock estimated within inventories made for forest management planning as well as within NFI measurements. Additionally, it should be highlighted that the problem of representativeness of equations was developed by different authors on different empirical material. Defined by Orzeł et al. (2006a), the share of pine's bark in the total stem volume (11.5%) is lower than the results of Rymer-Dudzińska (1997) research. It may result from estimating the volume of bark as a difference between over- and underbark volume of stem, determined by using overbark form factor equations applicable for country level (Bruchwald 1996) and coefficients for estimation underbark volume representative for research object (Orzeł 2006b). Unrepresentative empirical material used for elaborating expansion factors, i.e. not reflecting the diversity of level on which the indicator would be used, may lead to errors in biomass estimation (Lehtonen et al. 2004).

Significant problem related to BEF's evaluation is, moreover, a definitional issue associated with biomass of stump (i.e. part of stem remaining after tree cutting) and their possible inclusion in stem or merchantable growing stock volume. This problem will be discussed further in the next section; however, at this point should be noticed that default biomass expansion factors concern aboveground biomass from ground level (Penman et al. 2003).

4.4. Biomass conversion and expansion factors (BCEF)

Further IPCC guidelines developed in 2006 (Eggleston et al. 2006) for estimating the aboveground woody biomass on the basis of merchantable volume of growing stock, was proposed a new set of factors. A basis for diversity of BCEF in dependence on growing stock volume per hectare (Table 2) was functionally related to woody biomass and stand's volume stated inter alia by Brown et al. (1997).

The stock of the aboveground woody biomass in Polish forest estimated based on merchantable volume of growing stock (Table 5) and BCEF proposed for stands with growing stock over 200 m^3/ha (Table 2) amounts to 1757 million tons, i.e. by 60% more than the biomass of merchantable components of growing stock (Table 5) calculated with the use of basic wood density factors from Dietz's (1975) research. Because from methodological point of view, BCEF correspond to the product of density factors and biomass expansion factors (Eggleston et al. 2006), mentioned difference (60% of merchantable growing stock biomass) should be interpreted as woody biomass for growing stock components not included in inventory procedures. Biomass expansion factors for coniferous species resulting from the transformation of BCEF using basic wood density factors given by Dietz (1975) would be 1.66.

Biomass conversion and expansion factors proposed by IPCC (Eggleston et al. 2006) seem to be too high for Poland, which confirm inter alia research conducted by Wojtan et al. (2011). Developed by mentioned authors, conversion and expansion factor for the estimation of pine aboveground biomass on the base of stem volume is 0.547. Elaborated by Wojtan et al. (2011) indicator was described as BEF, but according to approach adopted in IPCC guidelines and in following work, it corresponds to BCEF definition. Biomass expansion factor resulting from transformation of BCEF proposed by Wojtan et al. (2011) using basic wood density for pine equalling 0.42 g/cm^3 (Table 1) is 1.30.

A source of BCEF proposed in IPCC guidelines for pine of temperate forests is probably Brown and Schroeder's (1999) thesis concerning biomass of pine stands in the United States. In thesis of mentioned authors, BCEF for pines stands for merchantable volume of growing stock over 100 m^3/ha is 0.81. In quoted publication originally, BEF term was used, but its description corresponds to BCEF according to approach used in IPCC guidelines and in following thesis. According to standards adopted in USA, merchantable volume of growing stock is defined underbark. Factor from Brown and Schroeder (1999) includes, therefore, additional estimation of inter alia bark biomass. From report prepared by the USA for FRA 2010 indicates that for conversion volume underbark to volume overbark is adopted 14% bark percentage (GFRA 2010). This means that in situation, when BCEF was supposed to be used in reference to growing stock in bark (like in Poland), it should amount around 0.7, which corresponds to value posted in IPCC guidelines from 2006 (Table 2).

Brown and Schroeder (1999) research covered five pine species, including *Pinus taeda* L., *Pinus echinata* Mill. and *Pinus virginiana* Mill. Generated factors refer to merchantable volume of growing stock, defined according to American standards. In United States, merchantable wood belong to volume of trees with minimum dbh underbark amounting 12.7 cm (5 in.). Additionally, dbh is measured from height 4.5 feet (137 cm), i.e. 7 cm higher than in Poland. Merchantable volume of growing stock concerns only stems measured without volume of branches to minimum diameter underbark amounting 10 cm in thinner end. Additionally, permanent stump height is applied, which is 30 cm (Brown, Schroeder 1999; GFRA 2010).

Definition of merchantable volume of growing stock adopted in USA causes that biomass conversion and expansion factors developed by Brown and Schroeder (1999) also estimate this part of growing stock, which is part of merchantable volume (undergoes inventory) in Poland. Merchantable volume of growing stock in Poland consists of stem and branches volume of minimum dbh and thickness in thinner end – 7 cm overbark (5 cm underbark). Default height of stump is 1/3 trees thickness on dbh.

In reference to theoretical height of stump should be explained that with the use of empirical formulas developed by Bruchwald et al. (2000) used in State Forests and NFI estimations (BULiGL 2013) is calculated volume of trees without volume of theoretical stump. For example, when calculating merchantable volume of trees with 30 cm dbh, adopted is theoretical stump height estimating 10 cm. Though in USA, volume of growing stock (merchantable components) does not include volume of stump (with permanent 30-cm height) still aboveground biomass is defined, however, from ground level (Brown, Schroeder 1999; GFRA 2010). This means that BCEF complement merchantable wood biomass of additional assessment of stump biomass.

On the definition of growing stock (over- or under-bark, above the stump or above the ground, with branches and top or without them) paid attention inter alia Konôpka et al. (2011). Mentioned authors distinguish above and below ground part of stump, including the above ground part to aboveground biomass. Similarly, Bijak et al. (2013) to below ground biomass included only part of stump located below ground (root crown). Socha and Wężyk (2004) and Zasada et al. (2008) did not precise unequivocally whether analysed by them trees were cut on ground level. On the other hand, inter alia Lehtonen et al. (2004) and Repola (2009) included above ground parts of stumps to belowground biomass. Similarly, Orzeł et al. (2006a) by the use of empirical formulas developed by Bruchwald et al. (2000) identified above ground biomass with volume above theoretical height of stump. As emphasised inter alia Somogyi et al. (2007) and Teobaldelli et al. (2009) adopted that expansion factors have to correspond with inventory data, in reference to which those indicators are used and on the basis of which they are determined.

5. Summary

Estimation of stock of woody biomass in forests at the country level requires having information about volume and structure of resources. National Forest Inventory carries out in Poland brings such data in reference to species and age structure.

Assessing biomass for large area demands many simplifications resulting from lack of knowledge about relation between known parameters such as merchantable volume of growing stock and particular components of tree biomass. That is why in process of woody biomass estimation for FAO (coordinated by Forest Research Institute) and UNFCCC (KOBiZE task), default factors proposed in international guidelines were used.

Our analysis indicates that default biomass conversion and expansion factors listed in IPCC guidelines (Eggleston et al. 2006) are not appropriate for Polish conditions because they lead to major overestimation of woody biomass in comparison to results obtained with the use of available local factors. Until there will be developed suitable national indicators based on representative material for whole Poland is recommended using biomass expansion factors listed in IPCC guidance (Penman et al. 2003). However, especially BEF for deciduous species seems to be too high for Polish conditions and requires verification.

Teobaldelli et al. (2009) as a drawback of default factors from IPCC guidelines (Penman et al. 2003, Eggleston et al. 2006) mention lack of definition of merchantable volume of growing stock and not taking into account the influence of variability (structure) of stands and individual trees on biomass stock. As a solution for that could be definition of BEF as a function of age or stand's growing stock volume (Lehtonen et al. 2004; Teobaldelli et al. 2009).

Wood density factors characterise strong positive correlation with age (Witkowska and Lachowicz 2013). Therefore, correctness of average factors applied for given species will be conditioned by compatibility of age structure of resources with the structure of sample on the basis of which density factors were defined.

Due to large differences of wood and bark density especially in case of pine, which is a dominant forest-forming species in Poland, calculations should be conducted separately for those components. As a result, a decrease of woody biomass stock in relation to stock presently reported based only on wood density factors should be expected. Default factors given in IPCC guidance (Penman et al. 2003) do not include differences in wood and bark density.

In case of forests on post-agriculture lands where lower basic wood density (Tomczak and Jelonek 2013) was stated, assessment of woody biomass changes within article 3.3 of Kyoto Protocol should not take place with the use of average density factors appropriate for forest land remaining forest land. Necessity of using different wood density factors for reporting carbon stock changes in woody biomass within Kyoto Protocol is motivated by low age of afforestation – activities from 1990.

Possibility of woody biomass estimation on country level with the use of empirical equations referring

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Authors' contribution

M.J. – concept, calculations, results analyze, literature review and manuscript preparation; P.B – literature review, manuscript preparation.

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