Annals of Forest Science (2016) 73:885–894
DOI 10.1007/s13595-016-0582-1

ORIGINAL PAPER

From inventory to consumer biomass availability—the ITOC model

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Received: 2 October 2015 / Accepted: 31 August 2016 / Published online: 9 November 2016

Abstract
• ***Key message*** **The application of the ITOC model allows the estimation of available biomass potentials from forests on the basis of National Forest Inventory data. The adaptation of the model to country-specific situations gives the possibility to further enhance the model calculations.**

• ***Context*** With the rising demand for energy from renewable sources, up-to-date information about the available amount of biomass on a sustainable basis coming from forests became of interest to a wide group of stakeholders. The complexity of answering the question about amounts of biomass potentials from forests thereby increases from the regional to the European level.
• ***Aims*** The described ITOC model aims at providing a tool to develop a comparable data basis for the actual biomass potentials for consumption.
• ***Methods*** The ITOC model uses a harmonized net annual increment from the National Forest Inventories as a default value for the potential harvestable volume of timber. The model then calculates the total theoretical potential of biomass resources from forests. By accounting for harvesting restrictions and losses, the theoretical potential of biomass resources from forests is reduced and the actual biomass potentials for consumption estimated.
• ***Results*** The results from ITOC model calculations account for the difference between the amounts of wood measured in the forests and the actual biomass potentials which might be available for consumption under the model assumptions.

Handling Editor: Jean-Michel Leban

Contribution of the co-authors Udo Mantau: basic idea of ITOC, writing the paper, and coordinating the whole process.
Thomas Gschwantner: writing the paper.
Alessandro Paletto: core group and tree components.
Marian L. Mayr: short-term scientific mission and writing paper.
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• ***Conclusion*** The gap between forest resource assessments and biomass potentials which are available for consumption can be addressed by using the ITOC model calculation results.

Keywords Biomass potential · Tree compartments · Conversion factors · Utilizable potential · Degree of utilization · Harvest losses · Utilization restrictions · Harmonization of inventory data

1 Introduction

Following the increased demand for energy from renewable sources in the European Union, the necessity for comparable information about availability potentials of forest biomass resources has increased. As an example, the EU Directive 2009/28/EC (Parliament and Council Directive on the promotion of the use of energy from renewable sources) sets mandatory national targets for the overall share of energy from renewable sources. If and how the demand for biomass resources from forests can be met thereafter became an increasingly pressing question.

Particularly, under the multiple objectives of contemporary forest management including nature conservation, natural hazard protection, recreation, water protection, and other forest ecosystem services, the assessment of such information needs to be able to account for a large number of influential factors. Thus, any assessment of the potential of forest resources has to integrate the various interests in the services and functions of forests.

In Europe, most countries conduct national forest inventories (NFIs) based on statistical sampling methods (Tomppo et al. 2010). National forest inventories aim at a comprehensive assessment of forest resources at country level and act as data providers for multiple purposes and for many national and international reporting processes, while at the same time, serving as the central information source and basis for decisions in forestry, forest economy and industry, and forest ecology. Scenario analyses based on the NFI sample plot data are used to support policy-making and future strategies (Eid et al. 2002; Backéus et al. 2005; Nuutinen et al. 2009).

With the increasing demand for biomass resources from forests, the potential supply and information on the actual biomass potential from forests at the market became of interest to a larger group of stakeholders. Studies on forest biomass availability were and are conducted in many countries (Malinen et al. 2001; Kärkkäinen et al. 2008; Röser et al. 2011). These studies have intensified the link between the forest sector and actors on wood and biomass markets and have subsequently revealed a number of unsolved questions. From a European perspective, the challenges related to the transformation of NFI data into actual biomass potentials for consumption arise from the following issues:

a. Substantial differences as regards the information on forest resources and their availability in countries of the EU. Most European countries conduct NFIs at regular time intervals and provide regularly updated forest resource information. Several countries are in the transition phase from stand-wise management plans and have not completed a second field assessment, not being able to provide estimates of increment and harvest. Thus, although most European countries have detailed data from NFIs, some regions lack up-to-date forest resource information.
b. The issue of differing country-specific definitions and methods of conducting NFIs. Within NFIs, the assessment of forest resources follows country-specific definitions (e.g.,

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for forest area, growing stock, and increment) and measurement methodologies. Many NFIs can convert their national estimates into harmonized results using conversion factors or functions. However, not all countries have developed such methodologies to derive harmonized and comparable information on forest resources.

c. The intensified link of the forest sector with an increasing number of stakeholders in the market for forest biomass resources has raised the importance of estimating losses along the production chain. During wood harvesting in the forests and its transport, losses occur that lead to a divergence between the amount of forest resources measured in NFIs and the amount of resources which are available to traders and processing industries along the value chain. Many of these losses have not been investigated.
d. Estimation of unregistered fellings. A part of the wood harvested and removed from the forest is not covered by official statistics (Jochem et al. 2015). It is mainly used for private purposes. In countries with many small forestland ownerships, this may constitute a considerable amount. However, the quantification of unregistered fellings is complicated because of information gaps. Nevertheless, it can be ascertained by indirect methods such as the wood resource balance (Mantau 2012) or a comparison of consecutive NFI results.
e. Following the traditional understanding of sustainability in forestry as to "not harvest more than grows again," it is common to compare net annual increment (NAI) with registered fellings as, for example, done in the sustainability indicator 3.1 "Increment and fellings" in the report on the State of Europe's Forests 2011 (Forest Europe, UNECE and FAO 2011). The calculation of felling rates (fellings as percent of net annual increment) may cause a significant underestimation, because of an imprecise definition for fellings, incorrect reporting of fellings (e.g., under bark instead of over bark), and incomplete recording of fellings.

Hence, reliable and comparable information on forest biomass resources at a European level require a transparent method of processing and handling the differences in data availability from NFIs. Under this given complex circumstances, the ITOC model was developed to provide a transparent calculation framework for the assessment of actual biomass potentials for consumption. The ITOC model primarily intends to bridge the gap between NFIs as data providers and the different assessments of use categories according to consumer information needs.

A methodological framework for constructing conversion methods (bridges) to harmonize data collected using national definitions and measurement methodologies was introduced by Ståhl et al. (2012). With this publication, we provide details about the bridges which were constructed to deal with the differences in input data availability and the different assessment of forest resources.

Data on the actual biomass potential for consumption were thought to reflect the information needs of, e.g., wood market analysts, wood processing industries, and actors from the bioenergy sector or chemistry sector and associated political players. Thus, we defined consumer information needs as the interest of all these actors in comparable data on the actual biomass potentials from European forests.

In the past, NFI data were directly interpreted by actors on biomass markets for the assessment of market availability which led to misinterpretations. The ITOC model serves these consumer information needs. It further provides a tool that aims at developing a transparent system of data exchange that is acceptable for forest inventory experts as well as for actors on biomass markets.

In setting up this tool that transforms NFI data to information on actual biomass potentials, an approach was developed that is flexible and able to cope with the described circumstances. The ITOC model is an excel-based calculation tool which is available at the publication list of the following website: https://sites.google.com/site/costactionfp1001/. Since the input data required for estimating actual biomass potentials for consumption is accessible from countries at different levels of detail, the tool follows a flexible approach. The ITOC model offers a dual approach consisting of a section which is based on input default values, taken from international reported statistical data and an adaptable country-specific section where a more detailed data availability can be processed.

2 Input data requirements for the ITOC calculations

The minimum input data requirements are kept low and consist of national data on forest land area available for wood supply (FAWS), the net annual increment (NAI), growing stock of broadleaf and conifer species, and registered fellings. For most countries in the EU, these data are available and default values can be obtained from international statistics (e.g., Forest Europe, UNECE and FAO 2011). Based on the minimum input data taken from international reported statistics, the ITOC model estimates the actual biomass potentials for consumption with the help of model specific parameters. In case of information availability from countries which exceeds the minimum input data requirements, the model allows for enhanced estimations taking into account country-specific information about NFI methodologies or forest management practices. With increasing quality of input information, the accuracy of calculation-outputs can then gradually be improved. In that way, the model ensures to provide estimates for all countries in Europe and to achieve an accurate assessment of actual biomass potentials for consumption at the European level.

Furthermore, the ITOC model can be applied to not only former and current NFI results, but also to scenarios of forest growth analyses in order to evaluate the future development under the defined assumptions. However, to calculate future developments of actual biomass potentials for consumption, the ITOC calculation framework is dependent on input data from growth projections and scenario analyses.

The model can be used to draw a Pan-European picture of biomass potentials from forests. The quality of model outputs can be improved by taking into account country-specific information.

Under the basic setting with a minimum of input data available, the ITOC model assumes the net annual increment as being an indicator for the amount of wood harvestable on a sustainable basis (Forest Europe, UNECE and FAO 2011). However, depending on the respective situation in a country, the net annual increment can be a more or less appropriate estimator for the harvestable amount of wood. The reasons for deviations between the net annual increment and the actual harvestable amount of wood on a sustainable basis are diverse and include the following:

a. Management strategies: Forest management follows silvicultural guidelines that can deviate in their envisaged harvests from the harvestable amount according to the net annual increment. Management strategies that seek to integrate multiple interests and objectives may also contribute to lower harvestable amounts.
b. Harvesting restrictions: Usually, the net annual increment is estimated for the productive part of the forest land. Although being productive, forest land can be subject to partial harvesting restrictions that implicate less intensive harvesting operations, i.e., less frequent and small amounts of biomass removal.
c. Age class distribution: The growing stock in a country can have a strongly skewed distribution. For example, countries with a large proportion of growing stock in the lower age classes can have a net annual increment which is higher than the achievable harvests.
d. Salvage logging after natural disturbances: The net annual increment is calculated by subtracting mortality from the gross annual increment. Natural losses according to the existing definitions of UNECE and FAO (2000), Forest Europe, UNECE and FAO (2011), and UNECE and FAO (2011) include mortality due to causes other than cutting by man, e.g., natural mortality, diseases, insect attacks, fire, wind throw, or other physical damage. In many countries, the wood from the affected areas is removed during salvage logging and enters the market. In such cases, the net annual increment will underestimate the potential of biomass being harvestable.

The results based on default values of the ITOC model calculations are realistic values in a generalized way and represent the overall and most likely situation. Thus, for countries with a minimum of data availability, the model can carry out all calculations based on data available from the Report on the State of Europe's Forests (Forest Europe, UNECE and FAO 2011). To make use of up-to-date information on national forest resources or projections, the model provides a separate section. In the separate model section, country-specific expert knowledge and potential harvestable volumes derived from national resource availability studies or growth model simulations can be used to improve the estimates. Both input data and model specific parameters (such as the parameters for losses and harvesting restrictions) can be edited. The results from the two different ways of calculating the potential biomass availability can be compared. The results table further offers the possibility to compare the calculated results of actual biomass potentials for consumption with the result potentials from EFISCEN in EUwood and EFSOS (Verkerk et al. 2010).

In Fig. 1, the calculation scheme of the ITOC model is illustrated.

3 Method and calculation steps of the ITOC model

The calculation of the actual biomass potentials for consumption with the ITOC model follows a stepwise procedure. The ITOC model calculation starts with defining a common starting point. The ITOC model uses the potential harvestable volume (PHV) on a sustainable basis as starting point for all further calculations. As a default value, the net annual increment of a country is assumed to represent the potential harvestable volume. Since the gross annual increment and consequently also the net annual increment are differently defined by NFIs

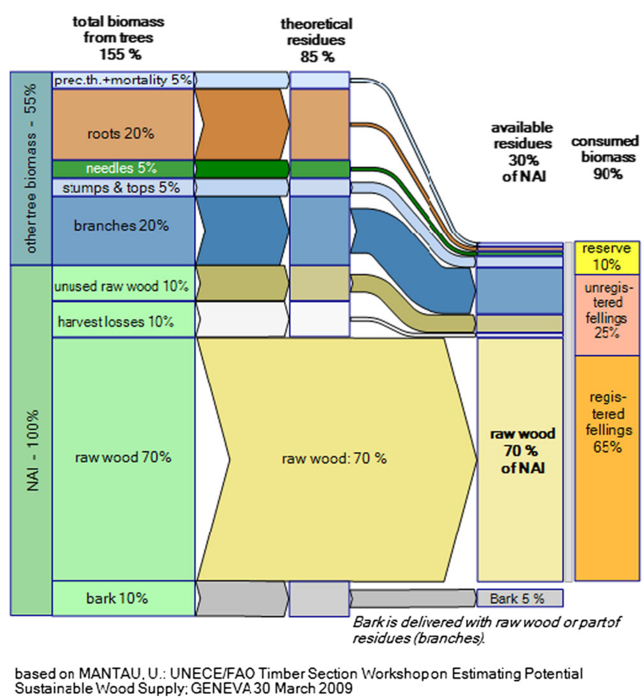

Fig. 1 Illustration of the ITOC model calculation steps to transform forest inventory data (e.g. NAI) to data on actual biomass potentials for consumption

(Tomppo et al. 2010), a harmonized net annual increment had to be defined for the ITOC model, in order to create a common and comparable basis for all following calculations.

For the harmonization of the net annual increment, the following methodology was applied. According to Päivinen and Köhl (2005), stem tops measured at 7 cm in diameter represent 1.7 % of tree volume, whereas tree stumps (the stem part between the "ground" and "above stump") in average account for 5.7 % of the total volume of the tree.

The influence of the minimum diameter at breast height (dbh) of a measuring methodology can vary considerably depending on the diameter distribution in a country. From the existing data available from Päivinen and Köhl (2005) and Tomter et al. (2012) and from the Austrian and German NFIs, a non-linear function was derived (Fig. 2) that describes the share of stem volume in percentage as the dbh threshold changes.

Referring to Päivinen and Köhl (2005), the calculated volume shares are based on the forest situation in Finland. Thus, the volume shares can only be transferred to other countries if the forests in these countries show a comparable structure. However, for representing the overall situation as intended by the default values of the ITOC model, the percentages for stem tops and stumps, and function (1) for volume differences depending on variations in measurement methodologies of NFIs are a suitable approximation. Table 1 shows the data used for deriving the non-linear function (Fig. 2).

This harmonization step takes into account country-specific differences in NFI measuring methodology concerning the minimum diameter at breast height (dbh threshold) and the inclusion or exclusion of stem tops and stumps. For the ITOC model, a forest economy-oriented harmonization of the net annual increment was chosen by defining a dbh threshold of 7 cm, and excluding the stump and all branches. This corresponds to the definition of the bole according to Gschwantner et al. (2009) given in Table 2.

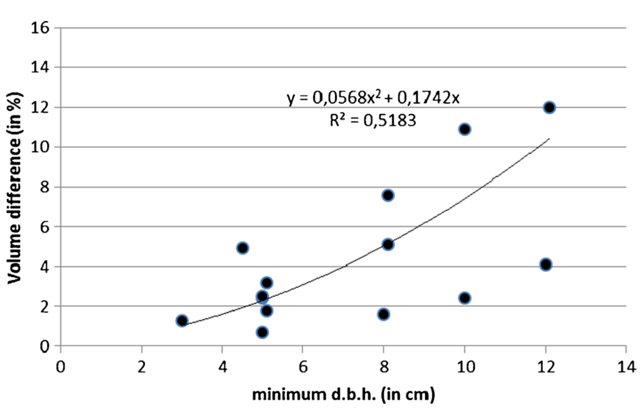

Fig. 2 Volume changes (in percent) in dependence on variations in diameter at breast height thresholds (in centimeters). Data from Austria, Finland, Germany, Greece, Italy, Norway, and Sweden. (Volume difference = $0.0568*dbh^2 + 0.1742*dbh$ (1))

Table 1 Data available for deriving a non-linear function describing the volume share below threshold values of diameters at breast height. Data sources used: Päivinen and Köhl (2005), Tomter et al. (2012), and data from the Austrian and German NFI

	Minimum dbh (in cm)	Volume difference (in %)
Italy	3.0	1.3
Italy	4.5	4.9
Greece	10.0	10.9
Norway	5.0	2.5
Finland	5.1	3.2
Sweden	5.1	1.8
Finland	8.1	7.6
Sweden	8.1	5.1
Finland	12.1	16.1
Sweden	12.1	12.0
Austria	5.0	0.7
Austria	8.0	1.6
Germany	10.0	2.4
Austria	12.0	4.1

After the potential harvestable volume is defined (default value = net annual increment) and a subsequent harmonization step carried out, the obtained volume estimates are expanded to account for the total biomass potential. The biomass expansion step aims at assessing a theoretical potential that includes all components of the whole tree. The biomass expansion thereby includes the conversion from stem volume to units of biomass and subsequent expansion to the individual tree components. The expansion is based on the partition approach and the definitions for the so-called tree components given by Gschwantner et al. (2009). This partition approach was developed during COST Action E43 and follows an additive and hierarchical scheme that allows establishing comparable volume or biomass estimates. The expansion factors which are based on a meta-analysis of several studies (see Table 3) were elaborated to account for the tree components: stem tops, branches, stump above-ground, and below ground biomass. The potential expansion factors were separately developed for softwood and hardwood species. The softwood and hardwood species considered in the meta-analysis reflect the most common species in Europe such as European beech (Cienciala et al. 2005; Koprivica et al. 2010; Skovsgaard and Nord-Larsen 2012), Norway spruce (Svoboda et al. 2006; Pajtík et al. 2008), Scots pine (Cienciala et al. 2006), Mediterranean pines (Garcia et al. 2004), and many species of oak (Garcia et al. 2004; Cienciala et al. 2008). In the meta-analysis, only studies carried out in Europe with species, number, and age of measured trees have been considered. The potential expansion factors were calculated by weighting based on the number of trees measured in each study and distinguishing between softwood and hardwood species.

Table 2 Definitions for tree components according to Gschwantner et al. (2009)

Tree component	Definition
Whole tree	The whole tree comprises all parts or organs of a tree, ranging from the leaves, flowers, fruits and buds to the branches, stem, roots, and fine roots.
Above-ground biomass Below-ground biomass	The above-ground part and the below-ground part of a tree are separated by the surface of the ground.
Above-ground lateral parts	The above-ground lateral parts of a tree are separated from the main stem by the theoretical intersection surface of the main stem.
Large branches	The large branches of a tree are the portion of the above-ground lateral parts with a diameter of more than or equal to the defined diameter threshold.
Small branches	The small branches of a tree are the portion of the above-ground lateral parts with a diameter of less than the defined diameter threshold.
Stem	The stem of a tree is the above-ground part of the main (off) shoot with apical dominance.
Stem top	The stem top of a tree is the topmost part of the stem from an over-bark base-diameter of the defined diameter threshold to the stem tip.
Bole	The bole of a tree is the above-ground part of the stem between the stump and the stem top.
Stump	The stump of a tree is the above-ground base part of the stem which would remain after a tree was cut under normal felling practices.
Foliage	The foliage of a tree comprises all above-ground temporary parts such as the leaves and needles, reproductive parts, and buds.
Bark	The bark of a tree includes all tissues of the main stem, lateral parts, and below-ground parts between the xylem and the epidermis of the phellem.

The expansion factors refer to the harmonized net annual increment and are given in Table 3. There, the harmonized net annual increment is set equal to 100 % and volume estimates in percentage values are added for tree components.

The biomass expansion using the model-specific default values assumes that the theoretical above-ground biomass is about 155.2 % for hardwood and 142.3 % for softwood in comparison to the harmonized net annual increment (100 %). The below-ground biomass potential is quite significant with about 21.8 % for hardwood and 23.0 % for softwood. Thus, the theoretical biomass potential from whole trees is about 177.0 % of the harmonized net annual increment for hardwood and 165.3 % for softwood, but may vary significantly among countries.

In practice, due to different reasons, not all tree components can or should be realistically harvested and removed from all

Table 3 Share of tree components in percent considering the harmonized net annual increment as 100 %. Our elaboration by Cairns et al. (1997), Cienciala et al. (2005, 2006, 2008), Fattorini et al. (2004), Garcia et al. (2004), Green et al. (2007), Koprivica (2010), Pajtík et al. (2008), Skovsgaard and Nord-Larsen (2012), Svoboda et al. (2006), and Tabacchi et al. (2011)

	Harmonized net annual increment = 100 %	
Tree components (%)	Hardwood	Softwood
Stem wood under bark	100.0	100.0
Branches and stem tops	33.5	24.0
Leaves and needles	5.0	5.0
Stumps (above-ground part)	4.2	2.5
Bark (stem)	12.6	10.9
Above-ground biomass	155.2	142.3
Below-ground biomass (roots)	21.8	23.0
Total biomass	177.0	165.3

forest sites on forestland available for wood supply. Such harvesting restrictions include and are commonly distinguished in the categories of technical, ecological, and economic restrictions. Table 4 describes the three types of harvesting restrictions with some modifications by referring to Hetsch (2009).

Technical and economical restrictions are in several cases correlated, when the profitable use of harvesting technologies is limited by economic considerations, and harvests are not realized because the achievable revenue will not cover the harvesting costs. Economic restrictions, however, are not taken into account by the default settings of the ITOC model calculation scheme. The target is to determine the harvestable biomass potential from forests under ecological and technological restrictions. The ecological restrictions depend very much on social conventions and can reveal short- and medium-term changes due to implementation progress of natural conservation programs.

For taking into account the harvesting restrictions, the ITOC model offers, apart from default percentages, the opportunity to enter the proportions at which the individual tree components can be removed from the forest sites under the respective circumstances in a country. Countries that conducted wood and biomass supply studies in many cases have estimates about the impact of these restrictions on the harvestable amount of wood.

Expert opinion and evaluation can also provide reliable estimates on the reduction of the theoretical potential by the various harvesting restrictions. In case of lacking expert evaluations for a country, the default values as proposed by the ITOC model can be used.

Table 4 Types of harvesting restrictions and their description (Hetsch 2009)

Type of harvesting restrictions	Description
Technical restrictions	• Lack of infrastructure, notably roads, but also equipment • Logistic factors, such as high dispersion of wood or residues • Information deficiency about location and characteristics of resources, market actors, prices, etc.
Ecological restrictions	• Designation of protected areas on forest land, e.g., ecosystem protection or soil and water protection • High environmental standards, e.g., guidelines for leaving deadwood and habitat trees in the forest or restriction on harvesting and techniques (e.g., clear cuts) or natural regeneration • Harvest limitations for leaves, branches, and stumps due to concerns about nutrient losses resulting from removal of these tree parts
Economical restrictions	• Low demand for wood and low price levels • High harvesting costs, mostly resulting from labor or capital costs influenced by terrain condition and infrastructure • Mismatch of available wood quality and needed wood quality (if, for example, there is no local demand for wood of a given type, often because there is no respective manufacturing plant within a reasonable transport radius, this wood will not get harvested) • Low developed market structures and limited market information

The default values represent the overall expert evaluation regarding the impact of harvesting restrictions. In Table 5, the default values for tree components removable under harvesting restrictions are shown.

The intensified link between the forest sector and actors on the wood and biomass markets implies the consideration of different kinds of losses. During harvesting operations, i.e., felling and forwarding, and transport from the harvesting location to the mill site, losses occur that reduce the actual biomass potential for consumption. The losses can be further distinguished into harvesting losses, measurement losses, logistic losses, and quality losses.

Harvesting losses are difficult to determine but may significantly reduce the availability of the biomass potentials. Losses due to measurement methods and trade guidelines have an even stronger impact on the available volume. Measurement losses result in an underestimation of the volume that is actually harvested as compared to the registered harvested volume. The difference in form of losses between standing tree volumes and the available volumes of felled trees that reach the mill site is assumed to be around 10 %. The ITOC model accounts for these losses but also considers the proportions of availability for the various losses. Based on the potential harvestable volume which is the basic data input in the ITOC model, an availability factor is applied to obtain the proportion of availability of the individual compartments for wood supply.

The following table (Table 5) represents theoretical proportions of various compartments of the potential harvestable volume (Schmitz et al. 2005; Dieter and Englert 2001). The availability factor is based on considerations of an expert group in Germany that quantified the factor of availability for different compartments of losses. The values in Table 5 are taken as default values for the calculations in the ITOC model. One should realize that these factors may differ a lot among countries. The overall availability of other woody

Table 5 ITOC model parameters for residues to get from proportions of the potential harvestable volume to the availability proportion. Percentage values for various residue assortments. The theoretical proportions are expert estimates based on Schmitz et al. (2005) and Dieter and Englert (2001)

Residues	Theoretical proportion (in %) to potential harvestable volume		Availability factor (in %)		Availability proportion (in %) to potential harvestable volume	
	Hardwood	Softwood	Hardwood	Softwood	Hardwood	Softwood
Stemwood losses	9.1	12.0	10.0	10.0	0.9	1.2
Unused stem wood	7.1	7.1	50.0	50.0	3.6	3.6
Bark	9.0	11.0	70.2	70.2	6.3	7.7
Branches	32.5	23.0	50.0	50.0	16.3	11.5
Tops	1.0	1.0	75.0	75.0	0.8	0.8
Needles	5.0	5.7	0.0	5.0	0.0	0.3
Roots	21.8	23.0	5.0	5.0	1.1	1.2
Precommercial thinning	1.0	1.0	100.0	100.0	1.0	1.0
Natural losses	5.0	5.0	10.0	10.0	5.0	5.0
Total	91.5	88.8	32.6	30.6	30.4	27.7

biomass using the model parameters is about 30 % (hardwood 30.4 %; softwood 27.7 %) of the theoretical biomass potentials. The various model-specific factors can be adapted to country-specific situations but are restricted by the availability of information. Considering all these factors, the consumable biomass volumes amount to approximately 70 % of the potential harvestable volume.

After having defined the actual biomass potentials for consumption using the ITOC calculations, the final step is to assess the biomass reserve available in a country. The ITOC model therefore balances the resulting biomass potentials with data from corresponding felling statistics in the countries. Even if the consumer biomass potential is calculated properly, the direct comparison with corresponding felling statistics can be misleading for several reasons. Forests are used in many instances for private purposes. In general, these fellings are legal, but in many cases not registered by felling statistics. If the consumer side is completely covered by empirical studies (e.g., including fuelwood consumption of private households, biomass power plants, etc.), the total consumption of forest resources could be calculated using the wood resource balance (Mantau 2012).

Study results using the wood resource balance indicate that the volume of unregistered fellings is significant. From 1987 to 2012, the percentage of unregistered fellings in Germany grew continuously in line with total market consumption. As Fig. 3 shows, the 5-year average of unregistered fellings increased from less than 10 % to more than 20 % with a pronounced increase after 2005 when oil prices doubled and energy wood demand increased.

Without considering unregistered fellings, the officially calculated fellings are significantly underestimated. However, when conclusions are drawn about the biomass potential of forests on a sustainable basis, this is an important part of the calculation and gains importance when scarcity of forest biomass increases.

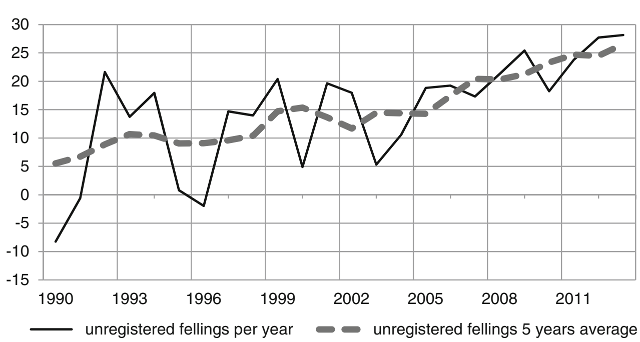

Fig. 3 Development of unregistered fellings in Germany between 1990 and 2011 in percent of total fellings (Mantau 2012)

Another possibility to estimate the amount of unregistered fellings is to compare the drain between two NFI periods to the fellings in the official felling statistics. The ITOC model applies a default value for unregistered fellings of 23.3 % of total fellings.

4 Application of the ITOC model—the case of Germany

To illustrate the calculation steps and the obtainable results of the ITOC model, an example based on data from the third NFI in Germany (Bundesministerium für Ernährung und Landwirtschaft 2014) is presented below. Figure 4 illustrates the forest resource situation in Germany in the year 2012. Biomass potentials from forests are depicted in volumes of cubic meter. The left side of the graph shows the ITOC model estimates for the theoretical potential of total biomass from trees in million cubic meters of standing volume (192.0 M m^3). This potential consists of the harmonized net annual increment as assumed to be an indicator for the amount of wood harvestable on a sustainable basis (121.6 M m^3) and a potential of 70.4 M m^3 of the other tree biomasses (in million cubic meters of solid wood equivalents) consisting of roots, stumps, stem tops, needles, and branches which have not been accounted for by the estimations of the net annual increment.

The graph then further illustrates the transformation process from the theoretical biomass potential to the actual biomass potential for consumption, and finally to the assessment of the available biomass reserve shown on the right side of the graph (in million cubic meters of solid wood equivalents).

The model-specific parameters account for harvesting restrictions and losses as well as for potential recovery rates of losses. This calculation step leads to a reduction of the total biomass to the actual biomass potentials for consumption differentiated by residues, raw wood, and bark potentials. The ITOC model calculation results indicate that the difference between the potential harvestable volume on a sustainable basis (net annual increment) as received from NFIs and the amounts of biomass potentials for consumption is small. However, for actors on biomass markets as well as for mobilization efforts, the information on the potential amounts of biomass assortments differentiated by raw wood, residues, and bark is of vital importance. The balance of the resulting actual biomass potentials for consumption with registered fellings and an assessment of unregistered fellings reveals the existing reserve. Thus, the overall reserve in Germany adds up to 27.8 M m^3 of solid

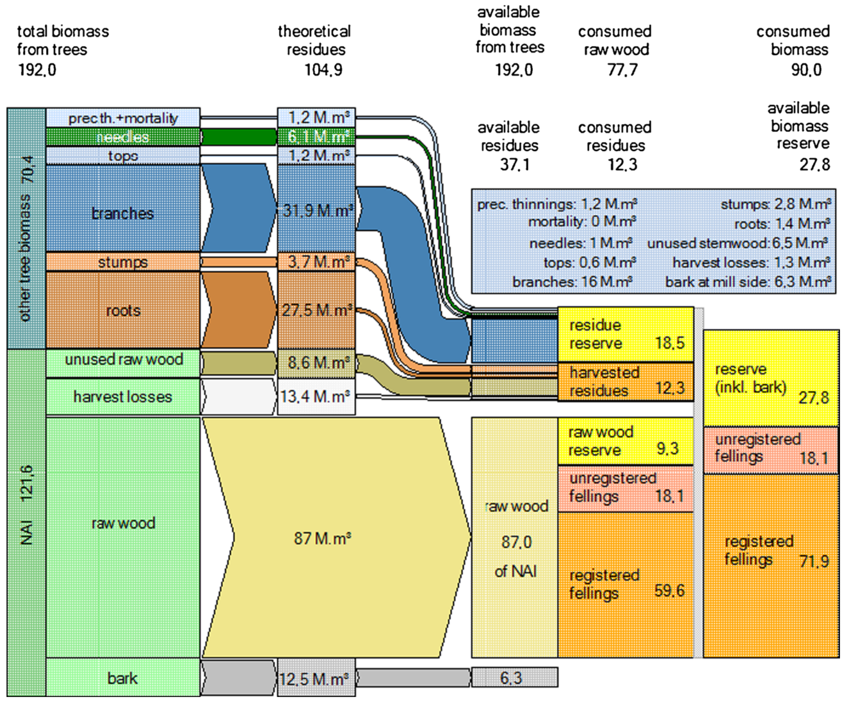

Fig. 4 Illustration of ITOC model calculations based on input data from the third NFI in Germany (Bundesministerium für Ernährung und Landwirtschaft 2014)

wood equivalents. This reserve consists of 9.3 M m^3 of raw wood and 18.5 M m^3 of residues.

5 Concluding remarks

The ITOC model is a tool to calculate the actual potentials of forest biomass resources harvestable on a sustainable basis. The ITOC model does not intend to answer the question of how much biomass from forests is actually available on the market and at what prices. The crucial factor of mobilization of biomass potentials is not included in the estimates generated by the model. Consequently, the quality of the calculation results depend on the availability of empirical input data and the model-specific conversion parameters. NFI results provide data that do not directly meet the information needs of actors at biomass markets. While NFIs aim at a comprehensive assessment of forest resources, actors at biomass markets are interested in the amount of biomass resources from forests that actually enter the market. Summing up, the ITOC model is an "interdisciplinary translation tool" between the output of forest inventories and the information needs of actors at biomass markets. The flexible approach of the calculations as regards the input data and model parameters provides the opportunity to make use of the best possible data sources available and delivers comparable results for actual biomass potentials from forests. The formulation of scenario assumptions offers the possibility of investigating the strengths and limitations of the ITOC model and to derive options of further enhancement.

Access to the ITOC model and conditions for using the model The ITOC model is available on the Internet from the website of Cost Action FP1001—https://sites.google.com/site/costactionfp1001/home

Any commercial use or use in research projects needs prior written acceptance from Udo Mantau.

Funding This research was supported by the Cost Action FP 1001.

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