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Preparing Emission Reporting from Forests: Use of National Forest Inventories in European Countries

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We examine the current status of greenhouse gas inventories of the sector Land Use, Land-Use Change and Forestry (LULUCF), in European countries, with specific focus on the utilization of National Forest Inventory (NFI) programs. LULUCF inventory is an integral part of the reporting obligations under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. The analysis is based on two questionnaires prepared by the COST Action E43 "Harmonisation of National Forest Inventories in Europe", which were answered by greenhouse gas reporting experts in European countries. The following major conclusions can be drawn from the analysis: 1) definitions used to obtain carbon pool change estimates vary widely among countries and are not directly comparable 2) NFIs play a key role for LULUCF greenhouse gas estimation and reporting under UNFCCC, and provide the fundamental data needed for the estimation of carbon stock changes covering not only living biomass, but increasingly also deadwood, litter and soil compartments. The study highlights the effects of adopting different definitions for two major reporting processes, namely UNFCCC and FAO, and exemplifies the effect of different tree diameter thresholds on carbon stock change estimates for Finland. The results demonstrate that more effort is needed to harmonize forest inventory estimates for the purpose of making the estimates of forest carbon pool changes comparable. This effort should lead to a better utilization of the data from the European NFI programs and improve the European greenhouse gas reporting.

Keywords forest carbon pools, greenhouse gas inventory, Kyoto Protocol, UNFCCC
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1 Introduction

The parties to the United Nations Framework Convention on Climate Change (UNFCCC or Conventions further in the text) are required to report annually their green-house gas emissions and removals by sources and sinks. The Convention aims at assessment, monitoring and reporting green-house gas emissions by sources and sinks, while the Kyoto Protocol (1997) aims at the actual reduction of emissions during its First Commitment Period (2008–2012). Greenhouse gas inventory and reporting also includes the "green" sector, i.e., Land Use, Land-Use Change and Forestry (LULUCF). Transparency and harmonization are among the key reporting issues, and are addressed by the specific monitoring guidelines developed by the Intergovernmental Panel on Climate Change (IPCC). For the LULUCF sector, Good Practice Guidance for LULUCF (IPCC 2003) must be followed when preparing the information on emissions from the LULUCF sector. Although this material provides detailed guidance, many issues remain open and are treated specifically by the individual member states. These issues, together with the flexibility in definitions, make the reporting country-specific and sometimes not directly comparable.

The member states of the European Union (EU) are all parties to the UNFCCC and its Kyoto Protocol. Hence, all member states prepare the annual emission report. Additionally, the formerly 15 member states of the EU represent a "bubble" (one entity) to the Kyoto Protocol with one common emission target. The LULUCF sector represents an important part of greenhouse gas balance in European countries. Specifically, forest is often recognized as an important manageable resource affecting greenhouse gas balance. Therefore, it is of vital importance to ensure that the European countries apply adequate inventory and monitoring systems that meet the requirements of Good Practice Guidance for LULUCF (IPCC 2003).

Sinks and sources should be reported for five carbon pools (aboveground biomass, belowground biomass, dead wood, litter and soil) by six different land use categories (forest land, cropland, grassland, wetlands, settlements and other land). Within each land-use category, carbon stock changes should be reported separately for lands with no change of land-use for over 20 years, and for lands converted from one category to another within the last 20 years, distinguishing also mineral and organic soils. The time period for reporting starts from a base year (1990 in most of the countries).

Frequently, the major inventory and monitoring resources used for LULUCF emission inventory in individual countries are the National Forest Inventory (NFI) programs. In some countries these programs began as early as the beginning of 20th Century and were gradually established in many European countries, mainly to assess the structure and quality of the volume of growing stock and its increment. NFI programs traditionally provided information vital to forest management policy, such as the applied and needed silvicultural and cutting regimes and the forest area by sub-categories. Later, NFI programs gradually expanded to provide information beyond traditional forestry purposes, such as forest health status. More recently, the information provided by NFIs has included biodiversity indicators and data permitting the assessment of carbon pools and their changes. Recently, the European Community started to compile its Member States' greenhouse gas inventory submissions under UNFCCC (EEA 2006, 2007). These reports include an overview on NFI programs in European countries, which

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indicate that most former EU 15 countries already deploy sample based forest inventories that support emission inventory of the LULUCF sector. EEA (2006) confirms the concerns previously articulated by Schoene (2003) on uncertainties when information on growing stock volumes, the central variable estimated by NFIs, is converted to carbon stock and carbon stock changes using biomass expansion factors. However, information on the specific extent of NFI programs to fulfill the LULUCF reporting requirements (coverage of five carbon pools), as well as the situation in the new EU member states is not available. Schoene (2003) also warned that uncertainty would be enhanced by adoption of different definitions, which would enhance discrepancies between reporting under UNFCCC and Forest Resource Assessment (FRA) of the FAO.

These above issues form the aims of our paper. We address the status of carbon reporting in the LULUCF sector in European countries on the basis of two questionnaire surveys conducted by the COST Action E43 "Harmonization of National Forest Inventories in Europe: Techniques for Common Reporting" (www.metla.fi/eu/cost/e43) (COST Action E43, 2007). These surveys were used to identify the level of NFI use in the LULUCF emission reporting process. Secondly, this paper also uses a case sensitivity analysis to demonstrate the likely effect of different definitions on carbon pool change estimates. Finally, we show that the information on forests carbon pools and pool changes recently submitted by individual countries under FAO and UNFCCC reporting may not be easily comparable. The reasons to the differences are discussed.

2 Material and Methods

This study was based on the analyses of two questionnaires. The first questionnaire gathered information about the applied definitions and the national interpretations of the Good Practice Guidance for LULUCF (IPCC 2003). The second questionnaire collected information on Kyoto Protocol related questions. The first questionnaire was distributed in early 2005 and the second in the spring of 2006. The questionnaires were sent to the country representatives involved in the Workgroup 2 of the COST Action E43 (COST Action E43 2007), which included experts technically responsible for compiling emission inventory in the respective countries or members of the collaborating inventory teams. Of the 25 countries, 19 responded to the first questionnaire and 22 to the second questionnaire, with most countries participating in both questionnaires (Fig. 1). The forest area of those countries that responded to at least one of the questionnaires, based on the FRA 2005 report and forest definitions used by the countries, was 155.6×10^6 hectares. The volume of growing stock on forest land in these countries was respectively 22.85×10^9 m^3. These figures comprise 93.6% of both the total forest area and the volume of growing stock on forest land of the 27 EU countries plus Iceland, Lichtenstein, Norway and Switzerland (FAO 2005). The questionnaire analysis was conducted in a straightforward manner by assessing the share of responses to individual questions. In a few cases, responses to obviously misunderstood questions were disregarded and treated as missing values.

The information on country-specific adoption of parameters of forest was obtained from the Initial Reports available at UNFCCC web site as submitted by countries by the end of 2006. At that time, the Initial Reports of the following European countries were available and used here: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lichtenstein, Lithuania, Luxemburg, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom. This is in total 25 countries.

As a sensitivity analysis example, the data from the 9th Finnish NFI cycle (1996 to 2003) were used (Tomppo 2006). The purpose was to demonstrate, with a simple example, the effect of different definitions on carbon pool change estimates. The methods employed in Finnish national greenhouse gas reporting were applied (Statistics Finland 2007). Two different forest area definitions and two different growing stock volume definitions were used.

Finally, to exemplify the differences between the reported information on carbon stock and stock changes under FAO and UNFCCC, respectively, we analyzed the information submit-

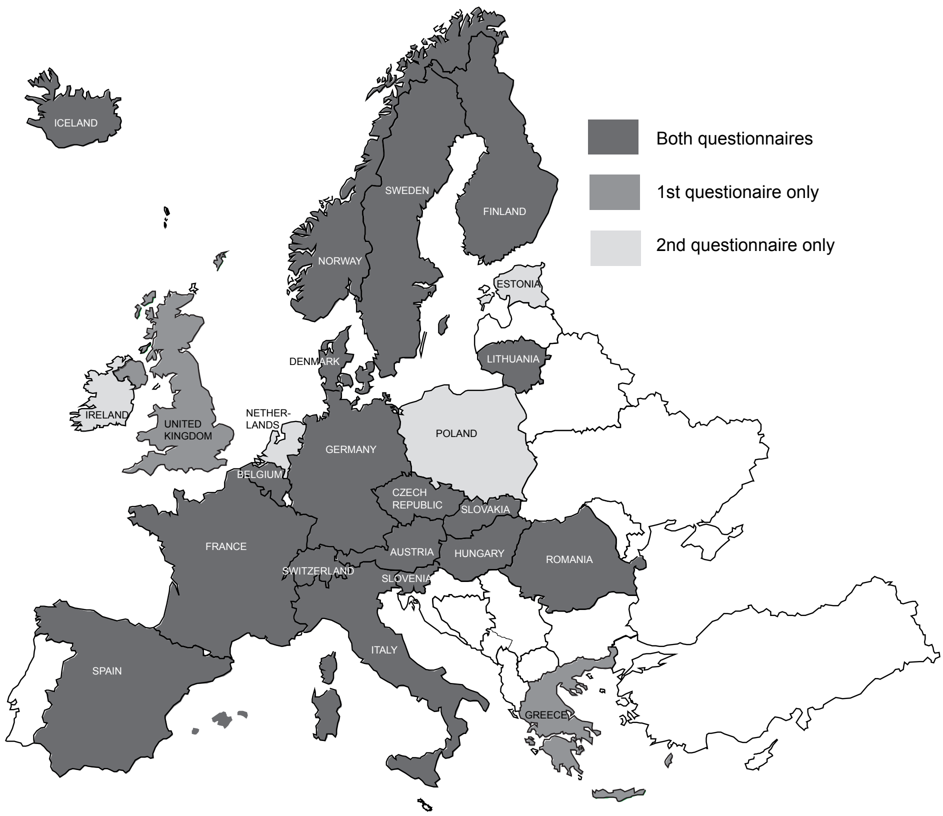

Fig. 1. European countries responding to the two questionnaire campaigns.

ted for a set of sample countries including the Czech Republic, Finland, Iceland and Sweden (UNFCCC 2007). For FAO, its Forestry department country tables "Carbon stock in forest and other wooded land" based on the Global Forest Resources Assessment 2005 (FAO 2005) were used. The carbon stock values reported for 1990 and 2005 were used to estimate carbon stock change in living biomass. The mean carbon stock change from the tables was estimated by dividing the stock difference between 2005 and 1990 by 15, i.e., the corresponding time period in years. The mean annual change as reported under FAO and the corresponding mean carbon stock change as obtained from the latest LULUCF common reporting format tables from the National emission inventory reports (latest reported year 2005) for the category of Forest land (5A) were compared.

3 Results and Discussion

3.1 Forest Definition

According to the Marrakesh Accords (UNFCCC 2002), parties to the Kyoto Protocol should define their forests within a predefined range of parameters: 1) minimum area from 0.05 to 1 ha, 2) minimum tree crown cover from 10 to 30% at maturity and 3) minimum tree height from 2 to 5 m at maturity in situ. The country-specific election of these parameters was reported in the Initial Report to the Kyoto Protocol with a deadline of the end of 2006. The forest parameters used by European countries for the purpose of Kyoto Protocol reporting for the LULUCF activities is summarized in Fig. 2.

Most frequent are the parameter values that correspond to the common FAO definition of forest, which includes the minimum area of 0.5 ha

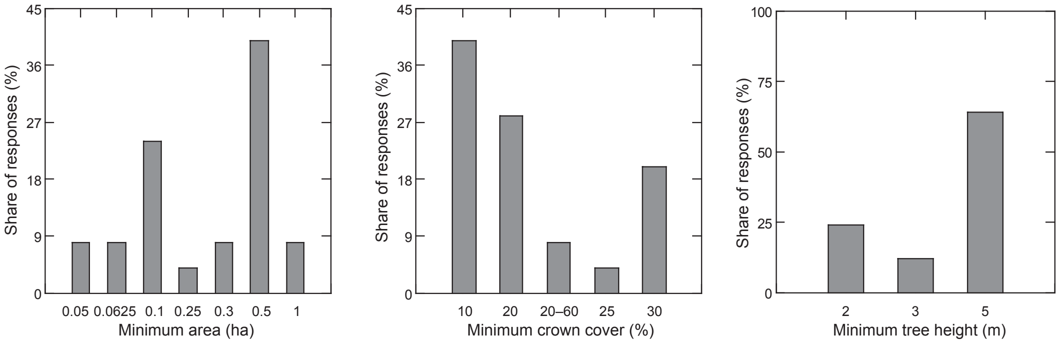

Fig. 2. Frequency diagrams of forest parameters as defined by 25 European countries in their Initial Report to the Kyoto Protocol: minimum area, minimum crown cover and minimum tree height at maturity.

(40% of the available responses), minimum crown cover of 10% (40% of the available responses) and minimum height of 5 m (64% of the available responses). However, the alternative values were also frequently elected within the prescribed range (with exception of crown cover parameter of 60% adopted by Switzerland). Actually, only seven countries (Denmark, Finland, France, Italy, Luxemburg, Norway and Sweden) adopted the definition with all three parameters matching the FAO standard. It means that the countries used the flexibility of the Kyoto Protocol and adopted definitions that most closely followed their national circumstances and tradition (Fig. 2).

Apart from the Kyoto Protocol's (Marrakesh Accords) forest definition requirements, Good Practice Guidance (GPG) for LULUCF (IPCC 2003) also asks for the minimum width of linear forest formations to be defined. However, only about two thirds of the available Initial Reports included this information. About a half of these reports indicated a minimum width of 20 m, about a third would use a value of 10 m, while a few remaining countries would use either 25 or 30 m as a threshold.

Forest area is certainly one on the key variables affecting the reported emissions. The adopted forest definition will be used when estimating emissions from the LULUCF activities. These include the obligatory activities of Afforestation/Reforestation and Deforestation under Art. 3.3, and the optional activity of Forest Management under Art. 3.4. It is obvious that differences in forest definition will have implications for comparability of the national emission (carbon stock change) estimates. Therefore, the Kyoto Protocol also seeks transparency and compatibility with the definition used for reporting to FAO. The parties to the Kyoto Protocol should justify in their Initial Report their selection of forest definition and provide an explanation once different parameter values are chosen for reporting as compared to those used for FAO reporting. While FAO reporting traditionally includes all forests, reporting under the Climate Convention is limited to managed forests. At the same time, the definition of managed forests remains country-specific and may vary from narrow to broad interpretation of management activities.

From the questionnaire responses, 80% of the countries consider all their forests as managed. For these countries, the forest area under the Convention and that used for FAO reporting should be identical provided that the same forest definition was used. Other countries report different forest areas under the Convention and for FAO. For example, Iceland excluded in its emission inventory all native forests, i.e. about 57% of its total forest area. Austria reports a forest area about 3% larger for UNFCCC than for FAO due to different thresholds of minimum height (2 m for UNFCCC and 5 m for FAO). France excludes 5% of its total forest area in UNFCCC reporting, specifically on parks and leisure forests and unmanaged mountain forests where inventories are not conducted. Until recently, Sweden excluded about 20% of its forest area for UNFCCC reporting; this was changed for the latest (2006) National Inventory

Report. The lands formerly excluded represented the areas where forest did not reach the production threshold given by the country specific definition of productive forest.

About 40% of the respondents replied that they included permanently unstocked areas within the reported forest land. The accuracy of reported data depends on the quality of the cadastral and/or other information on land use, which differs greatly in Europe. For example, several countries classify forestry roads, skidding tracks, timber yards, areas for game management and forest nurseries as permanently unstocked area. The differences in treatment of permanently unstocked areas within forest land would naturally yield differences in forest area. Hence, clear description of country-specific definitions and rules to handle land areas are important both for the Climate Convention and its soon-to-come Kyoto reporting.

Table 1. Methods (sometimes more than one per country) for land use transfers for reporting greenhouse gases to the UNFCCC (in % of all answers).

	%
Sampling (alone or in combination)	70
Land cover/use maps (alone or in combination)	32
Combining sample plots and maps	18
Other	27

Table 2. National systems and their ability to distinguish changes of land use (in % of all answers).

	%
Yes, based on NFI	32
Yes, based on cadastral and/or statistical information	27
Yes, with the support of cartography	9
Under preparation	32

3.2 Systems for Estimating Land Use Transfers

An implication of the methodological requirements set in GPG for LULUCF (IPCC 2003) is that land areas and carbon pool changes have to be reported separately for the land areas remaining in given land categories for at least 20 years prior to the inventory year and for land areas converted to the current land-use category within 20 years prior to the inventory year. Several approaches and their combinations were proposed to assess land use transfers (i.e., changes of land use categories). The basic approaches are sampling, land cover/use maps and use of other sources such as cadastral information and modern techniques providing information on lands, digital orthophotos and other remote sensing techniques. The choice of the methods used in the estimation of land areas in the responding countries is summarized in Table 1. Sampling is apparently the main approach used, sometimes supported by maps.

The key issue is the ability of the national systems to detect changes in land use. There is large variability in the responses received, and a noticeable amount of countries that were still analyzing the issue of land use detection (Table 2). Within the countries that are able to detect the changes, there are also differences concerning the time-period for revising the data: most of the countries declare themselves able to revise the information in 10-year periods, and several every 5 years. In any case, gap filling procedures to provide annual information are required. Gap filling is mostly based on interpolation or a regression estimate.

One important item related to land use and land use change, is the classification of land use categories used in the national systems. Only six countries answered this question with the number of adopted land-use classes ranging from 3 to 19. All specific national categories should be linked to the general IPCC (2003) definitions of land use categories for the reporting under UNFCCC. Other vital information linked to the reporting requirements is the availability of historical data required for adequate reporting of carbon stock changes in soil. Tier 1, the basic level of the reporting of stock change associated with land use, requires 20 years of land-use data prior to the actual year that is reported. Table 3 summarizes the historical information that is used at a national level about land use changes. About two thirds of the countries indicated to have some information about historical land use for the purpose of emission accounting since the base year (mostly 1990).

Table 3. The oldest year of land-use information used at national level (in % of all answers).

	%
Before 1970	36
Between 1970 and 1990	27
From 1990 to now	18
Not evaluated yet	18

Table 4. Application of the land representation approach of the GPG for LULUCF (IPCC 2003) and their combination, expressed in number of declaring countries.

	N
GPG 1 – Basic land-use data	6
GPG 1 and 2	3
GPG 2 – Survey of land use and land-use change	5
GPG 2 and 3	1
GPG 3 – Geographically explicit land-use data	5

In addition to the information on land use changes, the national systems should be able to detect the previous use of the land that was converted to other use. From the responses received, most of the countries (70%) believe their national systems would be able to do so. Only 5 countries declared to be unable to detect the former land use.

GPG for LULUCF (IPCC 2003) describes three basic approaches that may be used to represent land areas in an emission inventory. The basic approach (GPG 1) is the simplest one, applicable to countries with only basic land-use data. It enables only fundamental accounting of loss and gains for particular land-use categories. The more advanced approach (GPG 2) is a survey of land use and land-use change. This approach enables attribution of particular source land-use categories of land changing its status, i.e., distinguishing specific land use changes from and to respective land-use categories, as well as identification of the land areas that do not change. The most advanced and data demanding is the third approach (GPG 3), which is based on geographically explicit land use data. Table 4 summarizes the situation in European countries. All three approaches will be used about equally in Europe. Note, however, that countries are encouraged to constantly improve and develop their reporting systems. Potentially, all countries should be able to adopt at least the second approach, which permits detection of land use change, the central idea of the new inventory system introduced by GPG for LULUCF (IPCC 2003).

3.3 Five Carbon Pools

Good Practice Guidance for LULUCF (IPCC 2003) defines five components (pools) of ecosystem carbon stock, for which changes should be reported: 1) aboveground biomass, 2) belowground biomass, 3) deadwood, 4) litter and 5) soil. The following section describes aspects related to the estimation of these carbon pools.

3.3.1 Aboveground Biomass

Aboveground biomass includes only trees, i.e., ground vegetation, shrubs and herbaceous layers are excluded practically in all the responding countries. The only exception is Poland, which uses a specific definition for aboveground biomass that includes non-tree biomass.

Good Practice Guidance for LULUCF (IPCC 2003) lists two general methods to estimate carbon stock change of aboveground biomass, namely the default method and the stock change method. The default method is based on separate estimates of biomass increment and removal, while the stock change method uses the biomass estimates based on successive inventories. The stock change method can produce more accurate estimates if permanent sample plots or sufficient amount of temporary plots and thorough measurements are used. For the default method, either harvest statistics or other drain estimates based on permanent plots must be used. The stock-change method is mostly associated with sample based forest inventory programs with more than one cycle of data. The stock change method in combination with permanent plots has the advantage of discounting some uncertainty due to the covariance term that is subtracted under error propagation calculation. However, this does not hold if the consecutive biomass sampling is not from the same plots.

The questionnaire responses indicated that the default and stock change methods were applied about equally in European countries (41 and 45%, respectively). The remaining countries (14%) indicated that both methods would be used. This means that either a combination of methods is used, or these countries would initially use the default method and later, once the repeated NFI cycle is available, would use the stock-change method.

NFI programs traditionally provide data on merchantable growing stock volumes, while data on whole-tree biomass is needed to estimate biomass carbon pools. The approach to obtain biomass estimates depend on the kind of information available from forest inventories (e.g., Somogyi et al. 2007). When only aggregated estimates (stand level and higher) are available, then the biomass expansion factors (BEFs) are mostly used to expand and/or convert the estimated wood volume to estimates of total aboveground biomass. If tree level data are available, then the preferred tools to obtain total tree biomass estimates are biomass (allometric) functions (BF). Based on the questionnaires, the responding countries would predominantly rely on BEFs (38%), while 33% of the responding countries would use biomass functions. A similar number (24%) would use a combination of both BEFs and BF, which points out the approach of deriving BEFs on the basis of BF. An alternative explanation is that countries would change data sources and consequently the method of estimation as discussed above. A specific case is Hungary, where neither biomass functions nor BEFs are used, because biomass is directly estimated from the total tree volume estimates using known species-specific density factors.

Most of the BEF and BF were constructed from the country specific studies (77% of responding countries). To a smaller extent, international studies (41%) or IPCC default values (23%) were applied. This is promising information, as country-specific studies lead to a more accurate estimation of biomass as compared to IPCC default values. Therefore, it is also considered a good practice that countries develop their local biomass functions and factors that aid emission inventories (IPCC 2003).

3.3.2 Belowground Biomass

Good Practice Guidance for LULUCF (IPCC 2003) defines below-ground biomass as, "all living biomass of live roots except fine roots less than 2 mm diameter because these often cannot be distinguished from soil organic matter or litter". None of the responding countries considers non-tree biomass for estimation of below-ground biomass. Moreover, almost half of the responding countries include tree stump in the below-ground biomass estimation despite the fact that Good Practice for LULUCF (IPCC 2003) considers it to be included in the above-ground biomass.

The survey of methods applied for estimating belowground biomass did not provide concise information. Obviously, most of the countries will estimate this pool based on a combined approach using measurements (parameters of aboveground biomass), models (available functions) and IPCC or country-specific defaults (ratios between desired biomass quantity and the known/measured biomass component). However, about 50% of the responding countries would rely on IPCC defaults when estimating belowground biomass.

The question on the specific approach used to calculate belowground biomass revealed that mostly BEFs will be applied (68% of the responding countries). Other countries would use biomass functions or a combination of both BEFs and biomass functions (18 and 14%, respectively). This is a similar pattern as in the case of aboveground biomass described above.

Regarding source information, most countries would rely on BEFs and BFs derived from country specific data or those in international publications. A few countries (27%) would adopt default values of IPCC (2003). This information is also linked to that of above-ground biomass, because the estimation methods are based on that component.

3.3.3 Deadwood

Good Practice Guidance for LULUCF (IPCC 2003) defines deadwood as non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. In most responding countries, NFI would provide usable

Table 5. Deadwood, method of changes estimation (in % of all answers, multiple answers possible).

	%
Measurements	74
Models	37
IPCC defaults	21
Country defaults	5
Other	5

Table 6. Litter, inclusion of F and H horizons (in % of all answers).

	%
Yes	64
No	27
Undecided	9

Table 7. Litter, method of carbon stock estimation (in % of all answers, multiple answers possible).

	%
Measurements	36
Models	36
IPCC defaults	23
Country defaults	18
Other	23

data also on deadwood, which could be used to quantify changes of carbon stock held in this ecosystem pool. However, the responses differed largely as to the specific information collected. Different minimum diameter thresholds were used, ranging from 0 to 35 cm. The most common minimum diameter limit reported was 10 cm, which corresponds to the FAO definition (FAO 2005). Several countries also include height/length limits. Several countries adopt different limits for standing and lying deadwood. A large percentage of responding countries (86%) stated that their inventory includes standing dead trees within the deadwood component.

Changes in deadwood biomass, for forests remaining forests, will be based predominantly on direct measurements (Table 5). More than a third of the countries indicated some use of models to aid in the assessment. One fifth of the responding countries would use IPCC default values.

3.3.4 Litter

The litter pool is defined by the Good Practice Guidance for LULUCF as a layer including litter, humic and fumic layers (IPCC 2003). However, in several countries, the sampling scheme may treat these layers differently. When asked specifically on humic (H) and fumic (F) layers, the countries mostly reported inclusion of these layers within the litter pool (Table 6), which corresponds to the Good Practice Guidance for LULUCF. However, a large percentage (36%) of countries answered negatively to inclusion or remained undecided on this issue.

The question on estimation methods revealed that 36% of countries will use direct measurements of litter for the reporting purposes (Table 7). This is a high share that most likely includes those countries that understand measurements also to include collection of the very basic descriptive information on litter. Namely, many NFI programs remain limited to collecting the information on humus layer type and measurements of its thickness. Besides the measurements, many responding countries will use a modeling approach (Table 7). The rest of the countries (23%) will support their litter pool assessment by the IPCC default values, and a similar share (18%) of countries will use country-specific defaults.

3.3.5 Soil

The countries were asked if their inventory system provides separate estimates of carbon stock change for mineral and organic soil layers. The answers were somewhat inconsistent with the question on whether H and F layers are treated within litter. As mentioned above, almost two thirds of the responding countries included humic and fumic layers in the litter pool. However, only about one third of the countries (32%) declared that a country would provide separate estimates for organic and mineral soil layers (i.e., 68% would not be doing so). Based on the answers given for the litter pool, a larger share should be expected. Moreover, several countries plan to include the humus layer within the soil component. This is not in line with the Good Practice Guidance for LULUCF (IPCC 2003) definition,

Table 8. Soil, method of C-stock estimation (in % of all answers, multiple answers possible).

	%
Measurements	47
Models	53
IPCC defaults	37
Country defaults	11
Other	21
Undecided	18

but is acceptable once the country transparently describes its specific treatment of carbon pools and estimation methods. However, many countries remained undecided on the issue of soil carbon stock change estimation.

Good Practice Guidance for LULUCF (IPCC 2003) pays specific attention to organic soils such as peatlands, which are known to include very large quantities of carbon relative to other soil types and represent about one-third of the total soil carbon pool (Post et al. 1982). Also in some European countries, carbon reservoirs in organic soils are much larger than in mineral soils and biomass. Organic soils may also be more sensitive to environmental changes than mineral soils. Therefore, it is good practice to identify areas of organic soils and provide separate estimation of carbon stock change in them. From the responding countries, however, only 38% declared that their inventory system would provide separate estimates for mineral and organic soils, while 62% would not differentiate the two major soil categories.

The methods used for estimating soil carbon stock include measurement and/or models in most of the countries (Table 8). A large share of the countries would use the IPCC defaults to support their assessment. The responses indicated that most of the countries already selected a methodology to use for soil carbon pool change estimation. A rather large share of the responding countries reporting available soil measurements can be interpreted similarly as for the litter pool discussed above. For example, the assessment of soil type and soil thickness may have been considered as measurements supporting carbon stock change estimation of this pool.

3.4 Comparison of FAO and UNFCCC Reporting of Carbon Stock

Since 1947 the Food and Agriculture Organization of the United Nations (FAO) has, at 5 to 10 years intervals, aggregated and published data about forests and forestry of the world through their Forest Resource Assessment (FRA) programs (Holmgren and Persson 2002). The latest program was completed in 2005 with the publication of the 2005 Global Forest Resources Assessment report (FAO 2005). For the first time in the history of FRA, countries were instructed also to report carbon stocks in biomass, necromass and soil (FAO 2004a). On the other hand, the Climate Convention (UNFCCC), for the purpose of its emission inventory, collects the aggregated data on annual changes in carbon stocks in managed forest from all its parties (UNFCCC 2004). It is vital to note that in some cases, different organizations are responsible for the reporting under UNFCCC and for FAO. Hence, the reported data can both be rather similar or very different (Schoene 2003). Besides the organizational issues, inherent differences between the FAO and UNFCCC data are also caused by differences in adopted forest definition and treatment of managed/unmanaged forest area. These issues are discussed below.

The fundamental question important for understanding the likely differences between UNFCCC and FAO reporting is the adoption of forest definition. In the first questionnaire, 53% of the countries claimed they would use a national forest definition of forest in their UNFCCC reporting, while 42% of the countries would adopt the FAO definition. However, as shown above, the information compiled from the Initial Reports to the Kyoto Protocol showed that only 7 countries would adopt the general FAO definition, while other countries would use somewhat adapted definitions for their LULUCF reporting under Kyoto Protocol. Therefore, more inconsistencies should be expected between reported numbers on carbon stock and their changes as derived from FAO and UNFCCC submissions.

Another issue is the concept of managed forests. For FAO, carbon stocks are reported for all defined forests, while UNFCCC exclusively refers to managed forests. The definition of a managed

Table 9. Results of answers to questions about the consistency of carbon stock data reported to FRA and UNFCCC (in % of all answers).

	%
Identical authority for FRA and UNFCCC?	
Yes	41
No	59
Are the data for FRA and UNFCCC consistent?	
I don't know	18
Yes	32
No	50

forest is country-specific. While many countries may and do consider all their forests as managed, some countries differentiate substantial unmanaged forest areas.

Additionally, the organizational aspects of reporting may contribute to differences between the FAO and UNFCCC reporting. The questionnaire analyses revealed that the same agency was responsible for reporting for FAO and under UNFCCC in only 41% of the responding countries (Table 9). In some instances, the national correspondents did not know whether the data reported to FAO and UNFCCC were consistent. These correspondents mostly represented the countries where the reporting authority for FAO and UNFCCC was also different.

It is apparent that at the European level, the two key reporting processes, FAO and UNFCCC, are not based on identical definitions and information sources for estimating carbon stocks and can not be easily compared. Only a minority of the European countries report consistent data to both FAO and UNFCCC and for these countries carbon stock data from FAO and UNFCCC should be comparable.

3.4.1 UNFCCC and FAO Carbon Reporting: the Specific Conditions of Four Countries

We used the reported values for the Czech Republic, Finland, Iceland and Sweden to analyze and discuss the differences between the reported information on carbon stock and stock changes under FAO and UNFCCC, respectively, in these countries.

For the Czech Republic, the FAO Table of carbon stock held in living biomass reports 275 and 326 Tg C for 1990 and 2005, respectively. This gives a mean annual sink of 3.40 Tg C during this period. As for the UNFCCC common reporting format tables, the reported values of carbon stock change in forest biomass for the period 1990 to 2005 gave a mean annual sink of 1.86 Tg C. In this case, the mean carbon stock change reported under UNFCCC represents just about 55% of the estimate from FAO country tables. Obviously, this is caused by differences in the methodological approaches used, since different bodies were involved in the reporting for FAO and UNFCCC in the country. Specifically, the reporting under UNFCCC used a more detailed estimation method (Tier 2) with a default approach of specific estimation of increment and removals in biomass carbon pool on an annual basis. Additionally, burning of biomass residues were also included in the UNFCCC assessment, which also contributed to lower estimates as compared to those derived from FAO tables. However, the major quantitative difference must be caused by differences in assessment methods, i.e., Tier 1 based approach and stock change method for the FAO estimate versus Tier 2 methods and default method for assessing carbon stock change (IPCC 2003) used for the UNFCCC reporting.

For Finland, FAO FRA 2005 C content of trees for 1990 is 724 Tg (million tons) and for 2005 816 Tg. The average annual net sink is thus 6.13 Tg/year. Under UNFCCC LULUCF reporting the average annual net carbon sink in tree biomass is 7.10 Tg. This is about 16% more relative to the assessment from FAO FRA 2005 reporting. The main reasons for the differences are as follows.

1) The total drain in LULUCF reports was likely underestimated for the reporting period, which makes the UNFCCC sink estimate higher. The underestimated drain is due to increased share of biomass left to decay for biodiversity purposes and also due to a series of heavy windstorms. This is also reflected in increased amount of deadwood during 1990–2005, which is too low in the LULUCF reports. The previously applied estimate for natural losses came from the interval 1985–1995 and was likely too low. This was confirmed by the latest NFI campaign (NFI10; 2004–2008) and its unpublished dead wood estimates based on

Table 10. The mean carbon stock change in forest biomass as estimated from the UNFCCC reporting tables from the 2007 submissions applicable for the period between 1990 to 2005, and FAO carbon stock values of 1990 and 2005. The difference between the two estimates is expressed for the UNFCCC estimate relative to the FAO estimate (%).

	UNFCCC annual (Tg C/year)	FAO 1990 (Tg C)	FAO 2005 (Tg C)	FAO annual (Tg C/year)	UNFCCC/FAO (%)
Czech Republic	1.86	275	326	3.19	–45
Finland	7.10	724	816	6.13	+16
Iceland	0.022	1.17	1.61	0.029	–25
Sweden	9.49	1046	1170	8.27	+15

the measurements in 2004–2006 (Finnish Forest Research Institute, National Forest Inventory, personal communication 2007).

2) A high absolute sampling error of the stock change estimate based on temporary plots (used in FAO reports) compared to the default method (used in LULUCF) estimate may be responsible for some differences in the estimates of the two methods. For example, if the volume of growing stock is 2×10^9 m^3 and its relative standard error 0.5%, the error for the volume change estimate could be about 14×10^6 m^3. It is high compared, for instance, to the volume estimate of the increment minus drain of 30×10^6 m^3.

For Iceland, the calculations of FRA 2005 and UNFCCC are mostly based on the same data but differ in two points. First, they differ in the way C-stock and C-stock change is estimated. The FRA 2005 estimation of C-stock in the trees are based on 1) newly made single-tree biomass equations and 2) on growth simulations built on 2000 field measurements performed on 11 tree species. The latest UNFCCC estimate for Iceland is much simpler and uses only one general country specific coefficient for the mean annual C-sequestration in trees. Second, the FRA 2005 estimate includes native forests of mountain birch that are considered unmanaged forests. Hence, these forests were excluded in the UNFCCC estimates.

The FAO Table of carbon stock held in living biomass reports 1.17 and 1.61 Tg C for 1990 and 2005, respectively. This gives a mean annual sink of 0.029 Tg C. For the UNFCCC common reporting format tables, the reported values of carbon stock change in living biomass for the period 1990 to 2005 give a mean annual sink of 0.022 Tg C. In this case, the mean carbon stock change reported under UNFCCC quantitatively represents 75% of the estimates from the FAO tables. The FRA 2005 estimate of C-stock includes living biomass of other vegetation than trees. That explains a "false" increase in carbon between 1990 and 2005 because vegetated areas were transformed from the non-forest land-use classes to forest land and therefore resulted in an increased carbon stock of forest land without corresponding carbon removals from the atmosphere.

For Sweden, the average sink according to FAO/FRA 2005 is 8.26 Tg C annually in living biomass (period 1990–2005). Average carbon sink in living biomass (including aboveground as well as belowground parts) according to the most recent update of the UNFCCC reporting is 9.49 Tg C annually. This means that the UNFCCC values are about 15% higher that those assessed from the FAO tables.

There are several reasons for the difference between the estimates, although, they are based on the same data from the Swedish NFI. One reason is that the belowground biomass functions have recently been modified in Sweden. This change was reflected in the UNFCCC reporting but not in the FAO reporting. On average, the new functions provide higher values of root biomass, which is the reason for the higher sink estimate in the UNFCCC report. Another reason is that different estimation methods were used. The FAO estimate reflects a simple difference between two state estimates, whereas, the UNFCCC reporting is based on several consecutive change estimates from permanent plots. The latter approach should yield greater accuracy. This is similar as in the case of Finland as above.

Table 11. Utilization of NFI data for compiling information on five carbon pools to be reported according to the IPCC (2003) Good Practice Guidance for LULUCF (in % of all answers within individual pools).

	Yes	Yes, potentially	No
Aboveground biomass	91	9	0
Belowground biomass	56	13	31
Deadwood	74	26	0
Litter	50	28	22
Soil	53	29	18

A conclusion is that seemingly identical information provided on carbon stock or carbon stock change for the FAO and UNFCCC tables may yield rather different results. Similar or even larger differences can be expected for other European countries, especially for those where different reporting bodies are responsible for data submission under UNFCCC and FAO. This confirms the previous concerns of Schoene (2003). Now, several years later, the coherence of data reported under UNFCCC and FAO becomes even more vital and needs to be worked out. The above exercise is a striking example of a harmonization need where a rather simple intervention and collaboration could be expected to result in more credible and comparable information on forests and long-term development of carbon stock in European countries.

3.5 Use of NFI Data

Information required for estimating and reporting stock change in the five carbon pools under UNFCCC can, to a large degree, be supplied by or derived from the data of the NFI programs in the individual countries (Table 11). Almost all of the responding countries declared that their NFI would provide or potentially provide usable information on aboveground biomass. This is not surprising, because aboveground biomass is derived from growing stock, which is the prime information collected by NFIs. Additionally, most of the NFI programs also acquire data on deadwood, as almost 74% of the countries claimed that NFI data could be used to assess carbon held in deadwood. In many instances, estimation of carbon in litter and soil pools might also be based on the data collected in NFI programs. Only about 20% of countries declared that their NFIs cannot be used to provide usable information on litter and soil. The overall share of responses means that the use of NFI in the emission inventory of the LULUCF sector has already been clarified in most of the countries.

NFI is also a vital resource for information on land areas. The responding countries reported that NFI data would mostly be used when estimating land use transfers. Namely, more than 86% of the responding countries declared actual or potential utilization of data provided by NFI programs for this purpose. This is specifically important for the information required for the detection of afforestation/reforestation and deforestation (ARD) activities under Art. 3.3. of the Kyoto Protocol. Most of the countries report that NFI provides (59%) or may potentially provide (18%) data usable for ARD identification.

3.6 Example of Sensitivity Analysis

A vital issue is the likely impact of different definitions used in the process of carbon pool change estimates. Data measured under different definitions would be a straightforward way to assess these differences. For example, to assess the effect of a different tree diameter at breast height (DBH) threshold on biomass change estimates, the measured volume data or increment and drain data would be needed. These types of data sets are available at the moment only in a few countries in Europe. COST Action E43 currently develops tools to convert estimates measured with one definition to corresponding estimates based on another definition.

To demonstrate the effects of differences in forest definitions and DBH thresholds of trees on forest area and biomass change estimates we use data from Finland. Currently, Finland uses both a national definition and the FAO FRA 2000 definition (TBFRA 2000 definition) (FAO and UNECE/FAO 2000) in assessing land use classes in the field (e.g. Tomppo 2006). The FAO FRA definition was adopted in 1998, during the ninth national forest inventory (NFI9, 1996–2003).

FAO land use classes were assessed for field plots measured in 1996 and 1997 using models and available plot and stand level variables. The national forest definition of Finland is the same as in the two other Nordic countries, Sweden and Norway: forest is defined as a land capable of producing an annual increment of volume growing stock of at least 1 m^3/ha/a over the rotation under most favorable tree species composition, and not used for any other purpose than forestry or forestry related purposes. On the basis of NFI9, Finland's forest area increased from 20.34×10^6 hectares to 22.49×10^6 hectares when the FRA 2000 definition is used instead of the national definition. The volume of growing stock increased from 2037 to $2091 \times 10^6 m^3$ and the annual volume increment of the growing stock from 85.2 to $86.7 \times 10^6 m^3$, respectively. The relative increase in the volume and volume increment, and also in carbon sink, are lower than the increase in forest area because land considered by FAO FRA to be forest but considered to be non-forest on the basis of the national definition are on poor sites with low mean volume and low annual average increment.

One core question in forest inventories and also in UNFCCC LULUCF reporting is what type of trees should be included in the assessments. On the basis of Good Practice Guidance for LULUCF (IPCC 2003), all trees should be included, regardless of size, and also other vegetation than trees. The volume of growing stock based on the TBFRA 2000 definition includes all trees with a minimum height of 1.3 m, i.e., trees with a breast height diameter of 0 cm.

On the basis of COST E43 results, a DBH of 0 cm is the most commonly used threshold among the 21 responding countries. The volume of growing stock of these countries comprises 38% of the assessed volume of growing stock of all responding countries. The second and third most common DBH thresholds are 7.0 and 7.5 cm, with the volume of growing stock of these countries also a bit less than 40% of the volume of all the responding countries. Some European countries use even a threshold as great as 10 or 12 cm. Volume and volume increment estimates of Finnish forests would decrease noticeably if those DBH thresholds are used. For example, if a minimum DBH of 7.4 cm were used for Finnish forests, the volume of growing stock would decrease by 7%, while it would decrease by 14% with a DBH of 10.4 cm. The corresponding decrease in the increment would be 14% and 25% respectively. The decrease in the estimated carbon sink would be 15% and 26% respectively when the national reporting method is used, and the drain in these diameter classes is assumed to be zero (Statistics Finland 2007).

This simple example shows that the definitions used have a potentially high impact on the estimated carbon stock changes under the UNFCCC and Kyoto reporting. Thus, common definitions are of crucial importance to obtain comparable estimates among countries.

3.7 Reliability of the Questionnaire Results

This study was conducted as a questionnaire survey, with questionnaire forms submitted at two occasions to national experts within forest and land-use related reporting to the UNFCCC and the Kyoto Protocol. As in all questionnaire surveys the results depend on 1) the sampling approach, 2) the influence of non-responses, and 3) the potential of the respondents to correctly answer the questions. The last issue involves both the capacity of the respondents and the conciseness of the questionnaire as such. Contrary to most questionnaire surveys the entire population of interest (European countries) in principle was included, although some countries were not accessible through the network engaged to answer the questionnaires. This was treated as non-response. No follow-up on non-respondent countries was made, and thus, the results most likely have a certain bias regarding the state within the entire population of European countries. On the other hand, countries' response to the survey is clearly reported and, in fact, the results should mainly be considered as census results from these particular countries. With the latter interpretation non-response is not a problem. Further, test versions of the questionnaires were developed and applied in advance to a small group of people in order to avoid problems due to misinterpretations of the questions. Although this approach probably avoided a major portion of misinterpretations, some data quality problems were observed during the compilation of results. At that stage, obvious cases of misinterpretations were dropped from the analysis. For example, this concerned answers that constituted logically impossible combinations.

4 Conclusions

This material provides an evaluation of NFI programs in Europe in terms of supplying information needed for emission inventory on forestry under UNFCCC and Kyoto Protocol. It is obvious that NFI programs continuously evolve and gradually respond better to reporting needs. At present, NFI programs in most countries represent the major data source on forests supplying the essential information for quantifying aboveground biomass and deadwood. NFI programs also frequently provide the essential assessment of forest land area and areas of land-use transfers required for reporting afforestation, reforestation and deforestation activities. In many instances, NFI programs also provide vital information on litter and soil, although these components are represented less frequently and the quality of such information varies. Also, different methodologies used to sample soil and litter horizons will make it difficult to provide concise and comparable estimates of carbon stock change in soil and litter layer pools as defined by IPCC. We state that it is vital that the coherence of data reported under UNFCCC and FAO is worked out to ensure that information is matching and easily comparable. This would, however, also require a better coherence of definitions and methodological approaches. We conclude that further harmonization efforts are essential to ensure compatibility of the information collected from the individual countries, which should not be limited only for the purpose of emission inventory. The COST Action E43 is currently addressing these issues and attempts to develop tools to make the estimates based on different definitions comparable.

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