Multi-source inventory methods for quantifying carbon stocks and stock changes in European forests

CarboInvent

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Executive Summary

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CarboInvent

Project Summary Report

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Summary: **This document is the final project summary report and provides condensed information on scientific and practical results obtained within the CarboInvent project. The document was prepared as a compilation of summaries delivered by CarboInvent Work Package Leaders, namely:**

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List of Abbreviations

A	Afforestation
ARD	Afforestation, Reforestation, Deforestation
C	Carbon
CEF	Carbon expansion factor
CM	Crop Management
CO_2	Carbon Dioxide
COP	Conference of Parties (to the Kyoto Protocol)
D	Deforestation
DBH	Diameter at breast height
DEM	Digital elevation model
EFISCEN	European Forest Information Scenario Model
EO	Earth Observation
EU	European Union
FAO	Food and Agriculture Organization
FCCC	Framework Climate Change Convention
FM	Forest Management
FP	Framework Programme
GHG	Greenhouse Gases
GM	Grassland Management
GPG	Good Practice Guidance
GPG LULUCF	Good Practice Guidance for Land Use, Land Use Change and Forestry
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation

JRC	Joint Research Centre
KP	Kyoto Protocol
LU	Land Use
LUCF	Land Use Change and Forestry
LULUCF	Land Use, Land-Use Change, and Forestry
MA	Marrakesh Accords
MOP	Meeting of Parties (to the UNFCCC)
NFI	National Forest Inventory
OSU	Oregon State University
R	Reforestation
RMSE	Relative mean standard error
RV	Revegetation
SOC	Soil Organic Carbon
UNFCCC	UN Framework Climat Change Convention
WP	Work Package
YASSO	Dynamic soil carbon model
YC	Yield class

CarboInvent Project Overview

Project name:	Multi-Source Inventory Methods for Quantifying Carbon Stocks and Stock Changes in European Forests
RTD Programme:	Environment, and Sustainable Development
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Partner 2	**European Forest Institute**	**Finland**
Partner 3	**EC-Joint Research Centre**	**Italy**
Partner 4	**National University of Ireland, Dublin**	**Ireland**
Partner 5	**Finnish Forest Research Institute**	**Finland**
Partner 6	**Institute of Forest Ecosystem Research**	**Czech Republic**
Partner 7	**Potsdam Institute for Climate Impact Research**	**Germany**
Partner 8	**Hungarian Forest Research Institute**	**Hungary**
Partner 9	**Ghent University**	**Belgium**
Partner 10	**Austrian Federal Office and Research Centre for Forests**	**Austria**
Partner 11	**Swedish University of Agricultural Sciences**	**Sweden**
Partner 12	**University of Hamburg**	**Germany**
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<u>Introduction</u>

The United Nations Framework Convention on Climate Change (UNFCC) and the Kyoto Protocol (KP) belong in the realm of global policy making. However, these documents emerged from sound science foundations and they can both serve as prominent examples of climate change science impact on the global climate change policy. Currently, the KP is the major environmental policy effort on climate change. The Protocol contains well defined non-compliancy procedures if its requirements are not obeyed. This type of power is beyond any other international nature conservancy treaty. Consequently, forest monitoring for the KP and UNFCCC purposes deserves a great deal of interest.

All member states and EU as whole have ratified UNFCCC and KP. What is more, for the first commitment period (2008-2012) the EU set the GHG emission reduction target at 8% (when compared to the GHG emissions in 1990). This target is more challenging than the one required by KP, i.e. 6%.

According to Article 5.1 of the Protocol each Party to the KP should develop a ”national system for the estimation of anthropogenic emissions by sources and removals by sinks ...”. This system should follow requirements posed by Good Practice Guidance for Land Use, Land Use Change and Forestry (GPG LULUCF).

With the Kyoto Protocol coming into force, climate policy will be among the most important issues the years to come, and the key part of global political and economic controversies. The Kyoto Protocol as supplemented by the Marrakesh Accords defines the focal role of forest monitoring as a main tool for collecting information needed to fulfil reporting obligations and avoid / detect non-compliance.

CarboInvent project provides EU and its members with advanced knowledge on fulfilling reporting obligations through preparation of more advanced GHG inventories for the LULUCF sector. This also includes improving the comparability and harmonization of national systems when brought together to sum up to a continental-wide assessment of emissions and removals from forests. The project identified, developed and tested methods for assessment of carbon (C) stocks and stock changes in forests at national/EU levels for the purposes of UNFCCC and the KP, especially:

- To establish a set of biomass expansion factors for major EU forest types, to expand from inventory volume estimates to C content of tree components and to estimate their reliability.
- To develop a method for soil C assessment to be combined with forest inventories over large spatial scales.
- To develop combined field / remote sensing methods for assessing the local distribution of tree biomass and carbon stocks.
- To develop multi-source inventory methods for assessing C stock changes including regional distribution and uncertainties.

- To apply these methods in test sites and suggest upscaling methods to national level.

- To use remote sensing methods for stratification, to increase the accuracy of C stock and stock change estimates at the regional level.

- To calculate/improve regional and country data for stock changes in tree biomass and soils, including an uncertainty analysis.

In CarboInvent, two different approaches for integrating multi-source forest were applied. The “Top-down integration”, whereby existing aggregated data from forest inventories, combined with a large scale scenario models that allow calculation of carbon stocks and stock changes related to tree biomass and soil carbon pools. The “Bottom-up integration”, whereby the integration of remote sensing and field data by use of different tools and techniques already occurs at the plot or stand level; and the estimates are up-scaled to the regional, national level. Both integration methods are applied at the same test sites and their results are compared.

Results of the CarboInvent project merge input from the NFI data with extended terrestrial (soil, biomass) and satellite (delineation, stratification and area change detection) observations in order to obtain more precise estimates of carbon pools and their changes. Careful analysis of error propagation led to establishing confidence limits for quantities earlier associated only with qualitative assessment of uncertainties. Better understanding of variety of biomass expansion/conversion methods and of details of forest area change estimation led to advances in scientific understanding applicable also beyond LULUCF GHG inventories.

Within the Fifth Framework Programme, the CarboInvent project was one among the very few projects offering extension of the knowledge directly applicable to UNFCCC and KP reporting at EU and national level. Results presented below in a condensed form prove that the knowledge has really advanced as an outcome of the project.

1. Project networking and dissemination of results

The elaboration of Good Practice Guidance for Land Use, Land Use Change and Forestry (GPG LULUCF) is the most recent effort by the IPCC in response to the Marrakesh Accords (MA) invitation. The objective of this guidance is to facilitate the development of inventories that are transparent, well documented, consistent over time, complete, comparable, assessed for uncertainties, subject to quality control and assurance and, in principle, efficient in their use of resources available to inventory agencies.

The GPG LULUCF creates a framework for the measurement and reporting practices needed for UNFCCC and Kyoto Protocol reporting. The GPG LULUCF will be in force at least until the end of the first commitment period (2012). In addition, the development of GPG LULUCF is a step in IPCC's on-going programme of inventory development and will also support future revisions of the IPCC Guidelines themselves.

Data collected within the CarboInvent project is compiled and generalized in order to make them applicable for users beyond the project frame. This especially pertains to biomass expansion factors and soil carbon default data which are of particular interest to all groups working on carbon inventories worldwide. The same level of interest deals with results of methodological work from this project. In order to respond to such an interest, a workpackage (WP1) was established to provide data networking within and beyond the CarboInvent project and to bridge to other valuable data bases and research projects like CARBOEUROPE, CARBODATA, etc. as well as to disseminate the project results after its completion.

1.1. WP 1: Data requirements and data management

During the initial phase of the CarboInvent project, WP 1 was focussed on defining the data requirements of the major users and user groups. WP1 brought together data users (mainly sink reporting experts) and data providers (mainly the monitoring and scientific communities, national and EU agencies), in order to provide a platform with strategic aim in improved and harmonised inventories of emissions and sinks of GHGs from LULUCF-sector.

The implementation of this goal was based on three major efforts:

1) Creation of clearinghouse website (http://ghgdata.jrc.it/carboinvent/ciintro.cfm), to favour integration of the existing information at the European level.
2) Providing direct feedback into the design of WP1 deliverables from policy supporting activities of JRC within the EU Inventory system under governance of the Climate Change Committee
3) Providing availability of the project results to the public beyond the duration of the CarboInvent, through their implementation in the frame of the AFOLU Data project in FP7 Multiannual Workprogramme of JRC (see http://afoludata.jrc.it/index.cfm)

Appropriate data management policy was realized mainly by providing access to information and developing interfaces to databases managed by other workpackages.

Figure 1 (next page) presents overview of the general results achieved by CarboInvent, according to work package. Disseminating of the results is provided by the CarboInvent web page (www.joanneum.at/CarboInvent/) and the Carbodata data warehouse (visited through the European Forest Inventory Data Base - http://fi.jrc.it/). This allows downloads of the various default data, e.g. SOC default values for soil types by country, soil type and climate regions and uncertainty estimates. Further dissemination platform of results is provided by: (1) WEB-based information system (see below), (2) catalogue of data requirements elaborated together with WP8, (3) a database of project results (result integration and linkages of work packages), (4) a metadatabase of existing information relevant to forest carbon inventories, (5) supporting ‚compatibility and comparability of existing databases and national forest inventories, and finally (6) decision trees for the better exploitation of existing data.

A core activity within WP1 is the web page entitled: The Biomass Carbon Translator Databases where two user-friendly databases are accessible:

- The Biomass and volume equations for tree species in Europe (METLA, Finland)
- The Allometric Biomass and Carbon Factors Database (EC DG-JRC, Italy)

Face to face dissemination of the CarboInvent result was achieved through numerous workshops however, only two are listed here:

- “Land-use Related Choices under the Kyoto Protocol Obligations, Options and Methodologies for Defining Forest and Selecting Activities under Kyoto Protocol Article 3.4” was organized by Joanneum Research (with FAO, CarboEurope, INSEA and COST as co-organizers), in Graz / Austria in May, 2005. The workshop was targeted at policy and decision makers on KP issues related to LULUCF and staff of national agencies working on GHG reporting under the UNFCCC and the KP in Annex I countries. All reports and presentations as well as a comprehensive selection of background documents are available through the project website: http://www.joanneum.at/carboinvent/workshop/workshop02.html.

- “Practical national forest inventory systems to meet the requirements of the Kyoto Protocol”, organised by the Forest and Forest Products Research Institute, Japan, held in Nov. 2004. The workshop was targeted at GHG inventory makers. Workshop Proceedings are available at. http://cse.ffpri.affrc.go.jp/kanomata/index. html).

	Method development / testing
Biomass expansion factors WP 2 (6, 7)	web data base user guidance uncertainties and testing
Remote sensing WP 4 (7)	detecting ARD land detecting forest biomass
Forest Inventories (NFI) WP 6, 7 (4, 5, 8)	stand-/tree-/regional-level C estimates / upscaling uncertainty assessment and change detection cost efficiency remote sensing as auxiliary tool ability to detect ARD
Soil Inventories WP 3 (5, 6, 8)	ability to detect change if repeated plot-level and landscape level uncertainty sources inventory integration (NFI, research plots) upscaling soil carbon after afforestation role in sink reporting
Modelling WP 6 (3)	modelling SOC changes modelling biomass-C changes
Disturbance WP 5	role in GHG reporting
Dead Wood WP 5	role in existing inventories extension of an existing data base
Kyoto Protocol WP 8 (3)	requirements and result application

reports
summaries
for policy makers/stakeholders
peer reviewed articles
conferences

Allometric Biomass and Carbon Factors Database
http://fi.jrc.it/BEF_selection.cfm

CarboInvent web page
http://www.joanneum.ac.at/CarboInvent

CarboInvent
DATA AND INFORMATION EXCHANGE TOOL
http://ghgdata.jrc.it/carboinvent/ciintro.cfm

Figure 1: Overview of selected CarboInvent milestones relevant for GHG inventory makers and designers of reporting systems

2. Carbon inventory preparation, integration and comparison

Forest biomass and forest soil inventory data are the prime data sources to assess forest carbon changes. The available data can be used to in two different main methodical approaches: the top-down and bottom-up approach. It became a common routine by reporting agencies to use national forest inventory data and species dependent default values. These default values can be derived from either real measurements (plot-level data for the bottom-up approach), or taken from existing (aggregated) data bases/published data (data basis for top-down approach). Depending on the approach, different carbon stock and stock change estimates and related uncertainties are obtained. With regard to estimates for all five carbon pools in forest ecosystems, in particular concerning the combination of them in integrated monitoring schemes, the project significantly added to the existing knowledge as how to modify and optimize the existing monitoring or inventory schemes.

2.1. WP 2: Biomass expansion factors and biomass equations

WP2 was focused on the design and implementation of appropriate methods for assessing biomass carbon stock and stock changes at national level. The overall objective was to ensure that existing information on allometry of various tree species (expressed as biomass functions and conversion factors) are effectively exploited in and integrated to national forest inventories, in which inventory based variables (measured tree dimensions or volume estimates of stem wood) are expanded to whole tree biomass and carbon content. We also identified, quantified and reduced uncertainties related to the expansion from stem wood volumes to biomass and carbon contents of trees, by developing new reliable biomass expansion factors and biomass equations as well as assessing uncertainties of them. Furthermore, we developed and tested procedure for assessment of biomass carbon stock at national scale.

2.1.1. Database on allometric biomass and carbon factors (deliverable 2.1)

The CarboInvent project developed a database on allometric biomass and carbon factors (Seufert et al Deliverable 2.1 report). This database contains several types of factors that can be used to calculate biomass or carbon of forests from proxy variables. Depending on the proxy variables available, and method of the estimation, the following ***types of factors*** may be needed

- **wood density**: to *convert* volume of wood (m^3) to dry weight (tons) of wood (i.e., wood biomass);
- **Expansion factor**: to *expand* from a certain amount (volume or biomass), which includes some tree compartments, to another one that includes more or all tree compartments. The expansion factors include those that only involve above-ground compartments (e.g. to expand stem volume to total above-ground volume) and the so called root-to-shoot ratios that are the ratios of the root biomass to the above-ground biomass. Note that there are expansion factors that (1) expand tree-level data to tree-level data, (2) that expand stand-level data to

stand-level data, and (3) that expand from aggregate values (e.g. commercial harvest data) to other aggregate values (e.g. total biomass removed);

- **Carbon fraction**: to *convert* from biomass (t dry weight) to the amount of carbon (t C).
- **water content**: to *convert* from fresh biomass to dry biomass
- **Combinations of the above factors**.

The selection and use of these factors depends on the available initial values to be converted and/or expanded (referred to below and in the database as the "from what"), and the final values (referred to below and in the database as the "to what") that the user wants to calculate. Further guidance for the biomass inventories with these factors are provided in paper prepared by Somogyi et al (in revision).

2.1.2. Database on biomass equations and development of new biomass expansion factors and biomass equations

In this part of the project availability of information related to allometry of trees was evaluated and database of biomass and volume equations for tree species in Europe was developed by Zianis et al. (2005) (article available from www.metla.fi/silvafennica by end of 2005). This database provides tools for the carbon inventories that are based on tree-level data on diameter and height of the measured trees. According to the evaluation of the existing biomass equations, we conclude that biomass equations of Norway spruce, Scots pine and birch developed by (Marklund, 1988) can be applied in nation-wide carbon in northern Europe. In the temperate region several biomass equations are available, especially for Norway spruce, but few of them have regional coverage within their sampling. Due to reporting requirements under the UNFCCC representative biomass methods are needed. In this project Muukkonen (2005) developed generalized biomass equations for temperate region based on the biomass equation database (Zianis et al., 2005). These generalized equations can be used in the conditions where local representative equations are not available. In addition to compiled database of biomass equations and development of generalized equations for temperate forests, new biomass equations were developed for major tree species of temperate forests (Norway spruce, Scots pine, fir, larch, beech, oak, hornbeam, Sitka spruce and lodgepole pine).

If calculations are based on aggregated data (stem volume of growth estimates according to tree species and regions) biomass can be estimated with the help of representative biomass expansion factors (existing BEFs compiled, see Deliverable 2.1. database). In this project, BEFs with uncertainty estimation were developed for large-scale biomass inventories of boreal forests by Lehtonen et al. (2004). These age-dependent BEFs for Scots pine, Norway spruce and birch were developed by applying biomass equations of Marklund (1988) for trees measured in permanent sample plots in Finland. Foliage biomass estimation by BEFs, biomass equations and pipe model theory were tested by Lehtonen (2005). It was found that BEFs are suitable for regional biomass assessments, but not for estimating foliage biomass of single plots.

Biomass studies for Mediterranean countries have been very few (Zianis et al. 2005). In this project, biomass expansion factors (BEFs) were estimated for following species; *Eucalyptus globulus, Quercus faginea, Ulmus minor, Betula pendula, Pinus halepensis, Quercus cerrioides, Pinus pinaster, Pinus nigra, Quercus canariensis, Quercus ilex, Pinus pinea, Quercus humilis, Fraxinus excelsior, Castanea sativa, Alnus glutinosa, Pinus sylvestris, Populus nigra, Pinus uncinata, Quercus petraea, Pinus radiata, Populus tremula, Fagus sylvatica* and *Abies alba* (Sabate et al., 2005).

2.1.3. Estimation of national biomass carbon stock and stock change

This part of the project was focused on evaluation and development of procedures to be applied in national carbon stock and stock change of trees.

Guidance on use on BEFs and biomass equations in regional/national estimation of tree biomass was prepared (presentation by Z. Somogyi et al. in the final whole action meeting of COST E21 in Dublin. http://www.efi.fi/coste21/ftp/2004-10-06/Somogyi_etal_Oct_2004.ppt) and review paper on this issue was prepared (Somogyi et al., in revision). In this paper, a decision tree for selection of biomass estimation method is provided.

In this project we also made comparison between BEF approach and direct use of biomass equations with tree level data of national forest inventory in Sweden (Jalkanen et al., 2005). Both approaches are applicable for large scale inventories. The degree of uncertainty in both methods was highest in the young age-classes. At the regional level, the relative standard errors of the BEF-based biomass estimates were in the range of 4-13%. The age-dependent BEFs cannot be applied to conditions where stand development deviates from the conditions under which the BEFs were developed.

Age-dependent BEFs developed by Lehtonen et al. (2004) were also applied for the estimation of biomass carbon stock and carbon sink of vegetation in Finland (Liski et al. 2005). In this study we also derived carbon input to the soil based on these biomass estimates and assessed carbon balance of forest soil with the help of dynamic soil carbon model Yasso.

2.1.4. Conclusions

This project has made information on biomass equations and biomass expansion factors easily available for the users by compiling them into database and reporting them in the review paper. This information will improve quality and consistency of the biomass and carbon inventories in the European countries. Furthermore we have tested and developed methods applicable for biomass and carbon inventories and clarified terms and definitions used in the biomass estimation. The guidance developed in this project on indirect methods to estimate forest biomass will facilitate harmonization of the European inventories of forest biomass.

2.2. WP 3: Soil Carbon Inventories

Carbon in forest soils has recently received attention because small changes are expected to have tremendous effects on the terrestrial carbon balance. Carbon in soils and biomass are usually measured in spatially different inventories. Even though systematic grid-based soil inventories can be considered random, they are not representative in the statistical sense. Therefore, soil information cannot be directly upscaled without introducing additional error. Consideration of methodical requirements to upscaling and uncertainty assessment is the prime objective of the WP3 research approach (Table 1). With the results, each European country can now more precisely focus on the issue of soil Carbon in the greenhouse gas reporting.

Table 1: Overview and relevance of topics covered by CarboInvent Work Package 3

Deliverable	Title	Contents/results	Result application
D3.1	Validated, representative soil profiles under forest vegetation	– representativity (landscape scale) of plot inventories	– method development – uncertainty assessment – inventory planning
		– typical vertical soil C profiles	– data ranges for plausibility checks – importance of lower depth SOC
D3.2	Soil carbon default values relevant for evaluations of the carbon status of forest soils at regional, national, and European level	– Data compilation for test countries	– method presentation: SOC stock calculation – data ranges for plausibility checks – consideration of SOC in the evaluations in other work packages
D3.3	Methodology that links forest ecosystem with the regional carbon inventories	– literature review – model application in test area	– methodical review to integrate SOC inventories into other inventories: biomass, models, chronosequence studies, flux measurements (e.g. on Level II sites, or Integrated monitoring sites, or plot networks of other research projects) – methodical aspects relating to Tier 3 sink reporting
D3.4	Compilation and calculation of comparable soil carbon data according to the IPCC GHG inventory methodology	– presentation of results from D3.5 calculations – review on the role of SOC inventories in GHG reporting	– planning of SOC inventory for Kyoto Protocol reporting/development of a reporting systems including soils
D3.5-plot	Methodical standards to detect forest soil carbon stocks and stock changes related to land use change and forestry	– literature review including results from studies conducted by WP3 partners	– compilation of generic plot level uncertainties/systematic errors
D3.5-landscape		– evaluation of data provided by WP3 partners – test and methodical refinement of different upscaling methods	– comparison of different methods – uncertainty assessment of regional SOC uncertainties

The lack of data from repeated inventories strongly restricts the scope of this study to address to SOC changes. However, as mentioned above, the ability of change assessment is based on careful stratification, representativity and uncertainty assessments. The methodical aspects which need to be considered have been compiled.

The results of WP3 concentrate on the ability of existing soil inventories to detect SOC changes. None of the existing schemes has been designed to specifically track SOC changes given relatively short return intervals and the requirements to produce statistically reliable estimates. Small changes have to be detected against large background values. The soil storage compartment with most of the expected changes, the O-layer, is also the most variable one.

The most critical aspects of sampling forest soils for carbon are the high stone content in many soils, the lack of measured soil bulk density, and the lack of sufficiently covering spatial variability in particular that related to the forest floor. The litter layer as needed for the GHG reporting, is only partly measured: coarser organic residues are usually not sampled.

2.2.1. Representativity of soil inventories

Lack of representativity at both the plot level (micro-spatial variability), and within the whole inventory network (landscape level variability), are uncertainty sources often not quantified. At the plot level, and in the optimal case, 25 to 35 subsamples are needed to sample forest soils (including the O-layer). For national soil inventories, and for practicality reasons, at least 6 to 10 subplots are needed to take a representative sample from one site.

In order to investigate the representativity at the landscape level, WP3 has conducted a representativity analysis for the test area Thuringia, Figure 2 shows the plots which have been identified for additional sampling in order to optimize the regional representativity.

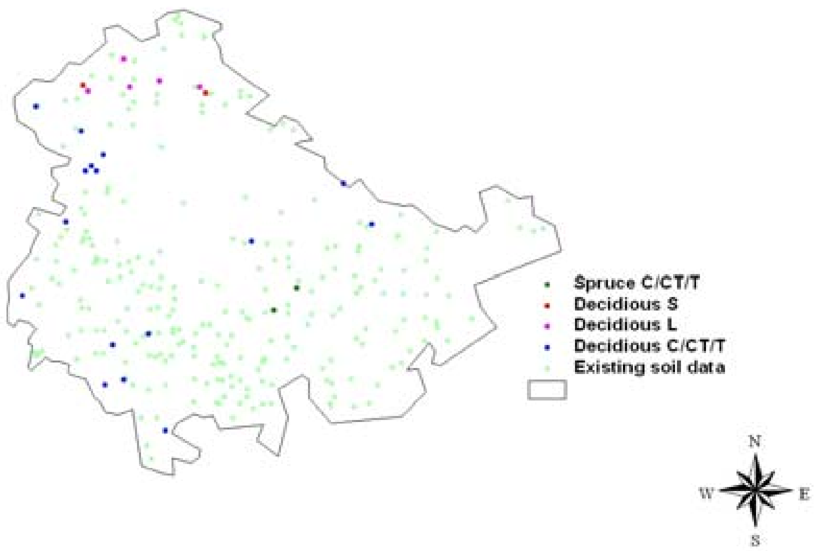

Figure 2: Selected NFI plots for soil sampling

The selected plots fill up underrepresented strata, such as loamy sites with deciduous forest types. N= 25 sites were sampled to optimize the coverage of the existing soil inventory. Now, with the availability of the new sites, a roughly 4x4 km plot density is avaibable for the test area). The locations for the new plots were selected among the national forest inventory (NFI) network.

Generation of high-resolution soil carbon baseline maps in three test countries and one test area with different plot densities

Existing maps allow the generation of high resolution soil carbon maps, which have the advantage that carbon data (including the model used to upscale those) can be connected to biomass data if they come from a different inventory grid. Figure 3 presents the forest soil carbon map of the test area Thuringia, a central German federal land. The evaluations have strictly separated the O-layer from the mineral soil 0-50 cm. The map is based on a 50 m DEM, an upscaled 1:10,000 forest site map (ca. 1:200,000), 100 m land cover data, and 250 m climate data. Also a map of liming activities was made available. The regression coefficients for the upscaling model are R^2 = 0.65 for the O-layer, and 0.55 for the mineral soil.

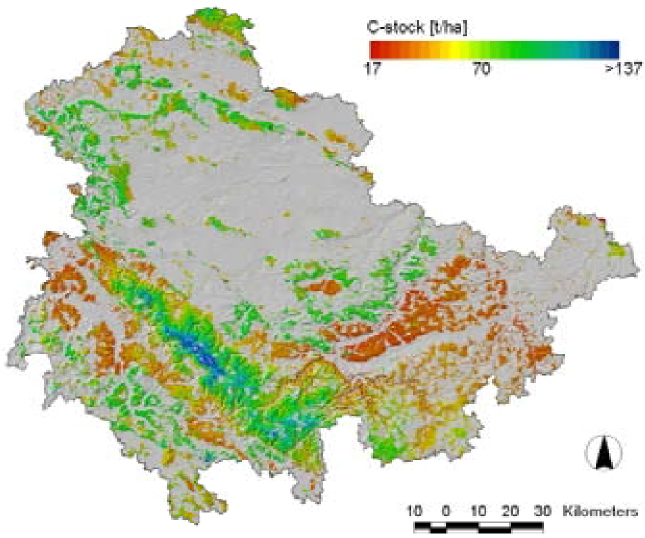

Figure 3: Map of the SOC stocks in the mineral soil of Thuringian forests [t/ha]

The data and model for Thuringia represents the best possible case for a regional soil C inventory (quality and resolution of the data including the maps; a previous study has devoted intensively to systematic sampling errors and solved these). It is thus used as the optimal model and serves as orientation for the development and quality analysis of upscaling models for other countries.

The predictors of the model can also be identified at any NFI plot (for example in a deviating inventory grid) given sufficient accuracy of the plot georeferencing. Connectivity between inventories is then possible in order to develop a Tier 3 reporting scheme based on the combined assessment of carbon storage pools.

2.2.2. Inventory uncertainties: related to the maps- and related to sampling

Figure 4 presents the kriging of the regression model error for the mineral soil carbon stocks (example: test area Austria). For the purpose of inventory planning, the forested area in zones with low predictive capacity of the model can be identified for the planning of additional sampling campaigns. In well-represented areas the inventory grid may be thinned out. The methodology will greatly improve SOC inventory planning and monitoring efficiency.

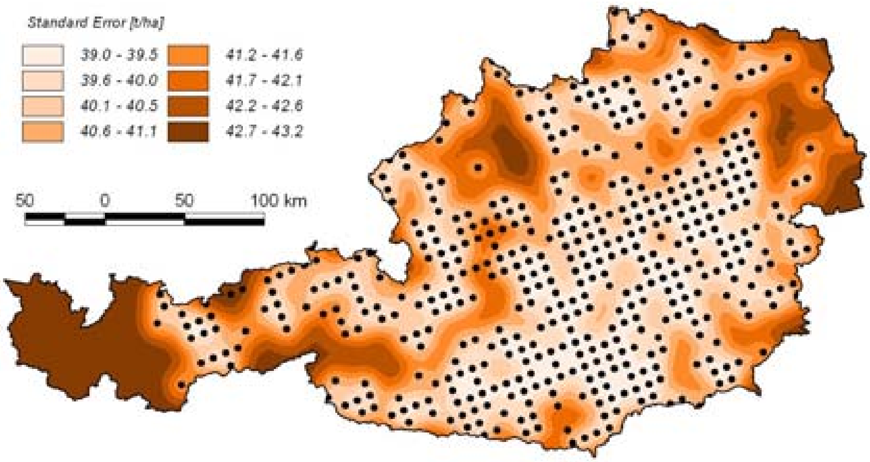

Figure 4: Spatial distribution of the inaccuracy (standard error) of the mineral soil carbon stock prediction in Austria; model: regression kriging

The regional error as the standard deviation from the plot evaluations and as random mean square error of the regression model can be quantified.

2.2.3. Capacity to detect changes from future repeated inventories

Given the availability of an unbiased soil carbon inventory and optimal representativity (see test area Thuringia), the repetition of the inventory can detect changes of e.g. 0.05 t C /ha/year within a time interval of **40 years**. It may be argued that any other more optimistic estimate for the same soil depth may not be based on sound error analysis and biased upscaling models.

2.2.4. Other results

- SOC default values for forest top soils in selected countries
- Discussion of the value of SOC inventories in the broader policy and research context
- Discussion of integrated aspects to inventory planning: forest ecosystem research/C cycles and Kyoto Protocol reporting aspects
- Modelling exercise (test country Spain)
- Detailed review of plot level error sources
- Elaboration of regional SOC predictors for typical European soil conditions

2.2.5. Conclusions

Large scale national forest soil inventories were investigated (e.g. Level I). The methodical framework has been presented to optimize each inventory for soil carbon change detection. The main conclusions are that refined error tracking is needed before the time frame and sample density can be determined which is required to detect change. The capacity of the existing national soil inventories for SOC detection suffers from the following limitations:

- lack of litter sampling
- insufficient number of subsamples per plot especially for the litter layer
- limited information about present and historical forest management and disturbances
- bulk density often not measured
- stones only visually assessed without calibration on the basis of measurements
- wrong conversion factors (Loss on Ignition) and erroneous recovery factors (wet oxidation)
- systematic inventory systems have typically representatvity gaps (especially in regions with fragmented forest distribution)
- the evaluation of large soil blocks (e.g. 0-50 cm) should be avoided; sampling and the evaluations should concentrate on those layers where changes actually occur. Deficiencies from not sampling at larger soil depths (or by not determining dissolved organic carbon in water solution, and soil inorganic carbon) may be compensated by intensive monitoring plots (e.g. Level II).

Due to these limitations, change detection mostly relies on the statistical sample error, which is believed to underestimate real uncertainties. In soil inventories, systematic error plays an important role, yet mostly ignored. Given these aspects, soil C changes cannot be easily detected with the existing inventories, and within the frame of the greenhouse gas reporting, unless only changes after land use change are considered. But even there, SOC changes were not detected significantly for a stratum (see also WP8 this study).

2.3. WP4: Remote sensing – method development and application

Within the CarboInvent project, remote sensing methods were applied for large area assessment of forest parameters. Data on stem volume, tree biomass and carbon stocks is in general only available for small areas, e.g. for sample plots, because the field measurements that are required to derive these parameters are very expensive. Therefore, earth observation images were combined with already available sample plot data from national forest inventories for wall to wall mapping (full aerial coverage) of stem volume, tree biomass and carbon stocks. For monitoring of deforestation, multi-temporal remote sensing images were assessed. Further, earth observation images were used to reduce the sampling error for large area estimation of stem volume, woody biomass, carbon stocks and stock changes by stratification.

The developed methods were applied and evaluated in Mediterranean (Spain), alpine (Austrian), boreal (Finnish) and temperate (German) test sites, which are representative for the major European forest ecosystem regions. The results demonstrate that the remote sensing methods are very cost effective tools for large area assessments.

2.3.1. Delineation of forest areas

The forest area maps are the basis for mapping forest parameters, for statistical large area estimation of forest parameters and for monitoring of changes over time, and are therefore of main importance for operational applications. Delineation of forests and non-forests with optical Earth Observation (EO) data has proven feasible with high accuracy. The accuracy that can be achieved depends on the nomenclature definitions, the EO and ancillary data that can be used, and on the forest ecosystem characteristics. Within the test sites, accuracies above 90% were achieved for delineation of forest areas with high resolution multi spectral data from the satellites Landsat and SPOT.

2.3.2. Mapping the local distribution of stem volume, tree biomass and carbon stocks

For mapping the local distribution of stem volume, tree biomass and carbon stocks, the remote sensing imagery were combined with field measurements from national forest inventories (NFI's). For all test sites, comprehensive data from NFI's based on systematic sampling of field plots were available.

For classification of stem volume, tree biomass and carbon stocks, the k-Nearest Neighbours Method (k-NN-method) was applied. In previous studies as well as for the applications in the test sites performed within CarboInvent, the reported estimation errors are high at the pixel level. However, the estimation error decreases when the size of the assessment unit increases e.g., when the pixel-based results are aggregated to larger assessment units. Therefore it is not recommended to use the results for mapping at the pixel level or for small areas such as forest stands, but to aggregate the classification results to larger assessment units e.g. at the municipality level.

2.3.3. Mapping deforestation with multi-temporal remote sensing imagery

According to the Kyoto Protocol, Annex B Parties must report carbon stock changes and non-CO2 greenhouse gas emissions during the commitment period on land areas that have been subject to direct human-induced deforestation activities since 1990. The definition of deforestation is given by the Marrakesh Accords. Deforestation for the purposes of the Kyoto Protocol involves the conversion of forest land to non-forest land.

Remote sensing methods were applied to evaluate the applicability of Landsat data for monitoring of deforestation in remote areas for which no field data e.g. from national forest inventories is available. As Landsat TM data from the 1990's and Landsat ETM+ data from the 2000's is available as archive data free of cost for most parts of the world (e.g. GLCF archive), this is of main interest for large area applications, especially for remote locations for which no higher resolution imagery is available (or cannot be purchased because of high data costs). Detectability of the deforestation events depends mainly on the minimum area definition, the spatial resolution of the remote sensing imagery and on the change characteristics. To improve the interpretation accuracy, methods for fusion of the panchromatic Landsat ETM+ data with the multi spectral bands were developed. The results show, that on the one hand, the Landsat data allows mapping of deforestation at a wall-to-wall basis at very low cost for most parts of the world with already available archive data, on the other hand, detectability with this data starts with large deforestation events of 1 ha. If quantification of deforestation including smaller deforestation events is required, in addition to the wall to wall mapping, estimation of the probability distribution of the aerial extend of the deforestation events is required. This can be estimated by sampling parts of the whole area with very high resolution EO imagery (e.g. IKONOS satellite data).

2.3.4. Generation of strata for large area estimation of stem volume, tree biomass and carbon stocks

To reduce the sampling error for the estimation of stem volume, tree biomass and carbon stocks for large areas, the remote sensing classification results were used for stratification. This method is especially relevant when estimates at the national level have to be performed e.g. for Kyoto Protocol reporting, where a high estimation accuracy is required. The estimation was performed as described in the chapter on the "bottom up approach". To derive the required strata, three different classification approaches were applied:

- Supervised maximum likelihood classification
- Unsupervised k-means classification
- K-NN classification

As the results show, all three methods have a high potential for reduction of the sampling error when the classification results are used for stratification. E.g., the Sampling error of the tree carbon stock estimates in the Thuringia test site could be reduced from 1.33 % to 0.21 % with this approach. For the estimate of the tree carbon stock in Pinus sylvestris, the sampling error could be reduced from 2.9 % to 0.7 % in the Thuringia test site. Compared to the field assessments, the application of the remote sensing methods can be achieved at very low cost. The integration of remote sensing classification results for large area estimation of forest parameters is therefore recommended.

2.3.5. Conclusions

The main conclusions are that remote sensing methods can optimally complement already available data from national forest inventories for large area assessment of carbon stocks and stock changes. Whereas national forest inventory data is in general only available for small sample plots, the remote sensing methods allow a wall to wall mapping (full aerial coverage) of forest parameters, especially stem volume, tree biomass and carbon stocks. Further, for estimation of carbon stocks and stock changes at the national level, the remote sensing classification results can be used for stratification to significantly reduce the sampling error of the estimates. The remote sensing methods were applied and evaluated in Mediterranean, alpine, boreal and temperate test sites, which are representative for the major European forest ecosystem regions. The results demonstrate that the remote sensing methods are very cost effective tools for large area assessments.

2.4. WP 5: Detecting carbon stock changes after disturbances and changes in forest management

Terrestrial ecosystems contain about three times the atmospheric carbon mass in living biomass and soil organic matter. Their annual gross fluxes exchange about 1/6 of the atmospheric carbon dioxide. The inter-annual variation in the biospheric net exchange fluxes is in the order of magnitude of fossil fuel emissions. This suggests that options of management for increased carbon storage in ecosystems may exist.

The Kyoto protocol, with article 3.4, opened an avenue to search how “additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex I“. During the work of COP guiding principles for the application of article 3.4 were developed stating it should be assured “that the implementation of land use, land-use change and forestry activities contributes to the conservation of biodiversity and sustainable use of natural resources” and “that accounting excludes removals resulting from:

(i) elevated carbon dioxide concentrations above their pre-industrial level;

(ii) indirect nitrogen deposition; and

(iii) the dynamic effects of age structure resulting from activities and practices before the reference year”. (Decision 11 of the 7th CP, draft decision -/CMP.1, Annex)“

If the instrument of sink management within forests is to be used there is a need to account for 2 groups of processes that reduce C stocks in forests, namely disturbances and forest harvesting activities. The aim of WP 5 was to analyse the state of knowledge on the effects of disturbance and forest management on carbon stocks in forests and to identify inventory methods for monitoring of these changes that are available or need to be further developed.

2.4.1. Monitoring of disturbance effects

Disturbances induce important changes in biogeochemical cycling and population dynamics. There are many aspects that are intensively studied in ecology. In spite of a growing body of information on these processes the current state of knowledge does not allow to set up a monitoring scheme that would allow for tracing all effects caused by the wide array of potential disturbances. However, with respect to lasting major changes in carbon stocks in forests, we conclude that it is recommendable to focus on stand replacing disturbance events, that lead to a sudden transfer of carbon from live trees to litter or from live trees and soil to the atmosphere. Under European conditions these are mainly fires and windthrow events. Other events, e.g. bark beetle attacks that spread and cause mortality at large spatial scales when not controlled, can be included in the

inventories from case to case as has been shown with our case study on a windthrow event in the Bavarian forest mountain range.
Based on a literature review we conclude that in order to capture C stock changes following fires it is necessary to monitor weather and climate variables at the time of the fire. This information can be taken from a nearby weather station. In combination with additional post-disturbance measurements on flame height as well as litter and O-horizon carbon content, this information can be used to model carbon lost from living vegetation and soils during the fire. Beyond this point the monitoring requirements for fire and windthrow effects are the same. In any case, information is needed on amount and quality of wood removed from the site and left on-site after the disturbance. In addition basic information on technical and mechanical equipment and procedures used during the salvage logging operation is required to estimate the (possible) loss of C from forest floor and soil carbon pools. The variables found necessary to be measured and ways to assess them are reported in detail in the final reports to WP 5.1 and 5.4. A questionnaire sent to researchers and forest managers revealed that interest in and knowledge about carbon dynamics following disturbances are developed in different intensity across Europe. For example, in countries with humid climates forest fire effects are of minor importance. Management in different countries is influenced by a multitude of possibilities and constraints for the forest enterprise (nature protection laws, work costs, product markets, etc.). Up to today no country in Europe seems to have a forest inventory in place that can deliver the full range of data needed to assess post-disturbance carbon stock changes. However, in some countries, additional information sources, as e.g. records of disturbance events including location, area affected and effect size exist. These can be combined with classical inventories in order to extract the information needed for Kyoto monitoring.

2.4.2. Decaying wood

The release of CO_2 from decaying wood is one of the main fluxes that need to be quantified when a substantial amount of wood is left on site after disturbances. There is little information available on decomposition rate constants and the variation with environmental conditions for European forests and tree species. The literature contains some studies conducted in boreal forests, but only a small number is available for the rest of Europe. Therefore, a method to estimate decomposition rate constants from published sources has been proposed and is included in the appendices' to the final report of WP 5.4. A database on dead wood dynamics was acquired from Prof. M. Harmon, OSU, Corvallis, amended with results on European tree species, and is available on the project's result webpage at JRC.

2.4.3. Monitoring effects of forest management

With regard to changes in forest management the main challenge was to define how "forest management" can be defined and to distinguish management options that in praxis often have shifting boundaries. At first, there are two levels of management that need to be distinguished: "Forest management in a wide sense" and "Forest management in a narrow sense" (see below).

FM in a narrow sense:	treatment schedule which best meets the objectives set for forest stands

FM in a wide sense:	FM in narrow sense + actions that shape external influences and legal constraints that frame the decisions taken at the individual forest management unit level

A list of forest management measures that can be applied at the stand level can be found in the WP5.5 report. The most prominent effects can be expected to be achieved with changes in rotation length and fertilization of forests that stock on nutrient poor soils. The use of irrigation is rather improbable because it would be needed in regions where conflicts about water use with other sectors can be expected.

2.4.4. Natural and indirect human induced effects

Although substantial progress has been made in recent decades to understand the effects of rising levels of atmospheric CO2, temperature rise and changes in other elements of physical climate, nutrient availability and pollutants, there are still substantial limitations to predictability of the effect sizes. Although hypotheses and elements for understanding of these processes were published and are further developed, a set of rules for prediction of the effect sizes that are commonly accepted within science has not yet been achieved. Thus, the individual factors that make carbon uptake and release vary cannot currently be identified and quantified, i.e. factoring out every single component from a composite flux is too high a burden for Kyoto reporting. The alternative interpretation of factoring out is based on the view that the aim is not to understand every single factor but rather to quantify the change imposed by application of a specific management measure, i.e. factoring out the direct human induced change. Then, the sources of variation due to indirect human induced effects and former management impacts need not to be identified and quantified individually. This can be achieved with paired comparison of stands that are treated in the “standard” way but subjected to all indirect effects to stands that are treated with a changed management regime but apart from this subjected to the same environmental conditions.

2.4.5. Policy options

Many climate protection options within the whole forest/wood industry cluster are accounted for in other articles then 3.3 or 3.4 of the Kyoto protocol. For example, the reduction of emissions that is achieved by substitution of fossil fuel intensive non-woody materials by wood is reducing emissions from industry and households for the whole country. Simulation results show that managed forests turn from an inferior to a superior choice if substitution effects are included in the evaluation. The generality of these results needs to be further assessed. As opposed to increases in stocks within the forest, substitution leads to cumulative effects (every harvest), so there is no sink limitation for this part of the sink. Thus, an evaluation of the whole set of policies and rules concerning wood use within the wider national concept for climate protection is needed when decisions on article 3.4 are to be taken. The same holds true for a wider range of policies if a sustainable use of forests, nature protection objectives, the provisioning of other goods and services than wood production and carbon storage need to be taken into account.

A large portfolio of methods to monitor timber volume changes exists that already allows to quantify a high percentage of FM-induced changes. Additional inventories need – in most cases – to be conducted for wood density, soil, dead wood, leaf litter, and ground vegetation carbon stocks. Biomass equations and BEF's (and the conditions of their use) can still be improved, especially in as much as roots are concerned. However, in most cases the methodology exists and needs just to be incorporated in existing inventory schemes. The main problem is that in many respects the baseline cases against which effects need to be evaluated by monitoring are not yet fixed. The baseline cases cannot be defined in one single way, but decisions to be taken depend on a detailed identification of policy objectives with respect to the Kyoto protocol and the role of articles 3.3 and 3.4 therein as well as with respect to other forestry related policy fields (nature protection, multi purpose forestry, sustainable use of natural resources, role of forest economy). Attempts to find answers to these open questions are part of the continuous negotiations of COP and define alternative policy options.
If forest management effects are to be assessed for detailed actions (e. g. different cutting regimes), it is of paramount importance to define and delimit such actions in a consistent way to be able to distinguish between different categories of FM activities (see final report of WP 5.5 for details). For the estimation of effects the technical systems used for conducting a specific activity and the area subject to this activity must be known. This information has thus to be included in reporting schemes.

2.4.6. Conclusions

Given that decisions are taken in one way or the other, the following conclusion can be drawn for individual monitoring instruments for verification purposes: If the detection of disturbance effects is by decision limited to major stand replacing disturbances this would – in the European context – mainly lead to the need of verification of carbon sinks and sources after major wind-throw and forest fire events. Then a combination of forest inventory data with additional statistical information on the area affected can be used. Current practice will have to be modified for these purposes. The legacy (age class) effect can be easily propagated with inventory information, given that a decision has been taken on how to deal with the dilution of a given age class structure by new external forcings that lead to changes in harvesting regimes. Other indirect human induced effects can be neglected; their monitoring can be kept in a permanent development phase or they can be factored out as a whole by using the technique of paired comparisons of forests with differing management strategies under consideration.

The results obtained with WP 5 will be integrated into several papers that are written in suite of the CarboInvent workshop held in Graz, Austria in May 2005 and the CarboEurope – GHG workshop held in Savonlinna, Finland in August 2005 and will be published with further journal contributions.

Finally, the WP5 of the CarboInvent:

- put forward a proposal for restriction of monitored disturbances to major stand replacing events,

- reviewed methods available for the monitoring of the effects of these disturbance events and proposed ways to complement standard inventories for this purpose,
- identified coarse woody debris as an important pool and provided a data base on decay constants,
- pointed to climate protection potentials in the use of wood that require an evaluation of article 3.4 related measures in a wider context of other national policies,
- discussed two alternative ways of factoring out: quantifying all natural and indirect human induced changes or quantifying the effect of a forest management option,
- pointed to policy options for further development of article 3.4

2.5. WP6: Top-down integration of BEF and soil carbon data with the existing forest inventories

The 'top-down integration' applies existing forest inventory data in their aggregated form (for example, tree species or tree species group per region in a country) for forest area, standing volume and increment. Volume estimates were expanded to total tree biomass carbon estimates per tree species and age class by using biomass expansion factors (BEFs) from WP2.

2.5.1. Method

Carbon budgets were calculated for the six European countries (Austria, Finland, Sweden, Spain, Ireland and Germany) using an existing modelling framework, the European Forest Information Scenario Model EFISCEN (Karjalainen et al. 2003; Pussinen et al. 2001). The EFISCEN model was run until 2015, assuming that harvest levels would remain constant after 2005. Carbon stock changes were calculated from stock changes over the period of time considered.

EFISCEN was originally developed to project the impact of management and climate change scenarios on the development of the growing stock of large-scale forests. In many EU countries, EFISCEN was applied to investigate forest development based on different forest management strategies and climate scenarios (Nabuurs et al. 2003, Schelhaas et al. 2005). To connect the new results from the CarboInvent project with the published scenario results and to be able to use the same model input and model parameters it was advantageous to apply the same model. Moreover, with EFISCEN and especially with the sub-model YASSO, rough estimates for the amount of soil carbon and soil carbon changes could be done. However, beside all the benefits, the model has some limitations. As EFISCEN is a scenario model designed for longer time periods and large regions, it is not optimized for small-scale predictions (space and time). Moreover, model results for sub-regions are often not representative, especially if the forest structure varies throughout a country (Thürig and Schelhaas 2006). Therefore, sub-divisions of the forest area for homogeneous regions as demanded in the GHG reporting can not be done. Moreover, EFISCEN requires input data stratified for stand-age classes. It is therefore not possible to make projections for un-evenaged forests. Because of these limitations, countries are not expected to apply EFISCEN in their GHG reporting of carbon stock changes in forests. However, the carbon change estimate done with EFISCEN gives a valuable indication of the upper end of the uncertainty of carbon stock-changes estimates. Together with the estimates done in WP7, indicating the lower end of the uncertainty, the range of how the estimates for carbon stock changes could be assessed.

Initial (1995) biomass carbon stocks ranged between 25 and 50 Mg C ha-1 in Spain, Ireland, Sweden and Finland, and between 100 and 110 Mg C ha-1 in Germany and Austria. Differences in the mean carbon stocks per hectare can be related to the mean volumes per hectare. High per hectare volumes in Germany and Austria resulted in high biomass carbon stocks compared to the other countries.

In all of the six test countries, carbon stocks increased over time. It was assumed that no changes in the forest area occur during the simulation period; therefore, the trend of the carbon stocks is affected only by fellings and by ageing of the forests.
The accuracy of the results for the biomass carbon stocks depends greatly on the quality of the utilised inventory data, and on the adequacy and representativeness of the applied biomass functions. The quality of the forest inventory data varies between countries. Adequate biomass functions were available for boreal conditions, as well as for spruce, beech and pine in central Europe, but representative data for other species/regions was scarce. Biomass carbon stock changes depend on the difference between increment and fellings. While average increment rates usually do not change drastically over the course of 20 years when large forest areas are considered, felling levels depend on many fluctuating factors such as market prices, wood demand and the occurrence of natural disturbances like storms. Therefore, our modelled tree biomass changes may deviate considerably from reality.

Soil carbon stocks were assessed by combining tree carbon pools with compartment-specific turnover rates to estimate the litter input to the soil. This litter is given as input to the dynamic soil carbon model YASSO, which simulates litter decomposition. Mean soil C stocks ranged between 60 and 90 Mg C ha-1 in Spain, Ireland, Finland and Sweden, and were around 130 Mg C ha-1 in Germany and Austria.

2.5.2. Results

National soil carbon estimates from WP3 were 50-70% lower than our modelled values for Finland, Sweden, Germany and Austria. For Ireland and Spain, the soil carbon estimates from WP3 were higher than our model results. Among the possible explanations for the variation between model results and soil carbon estimates are: (1) the fact that WP3 only considered carbon down to 20 cm, while YASSO is assumed to simulate soil carbon down to 1 m, (2) the equilibrium assumption in Yasso, which is unrealistic in the light of past changes in forest management and environmental conditions, and (3) the overestimation of decomposition rates on organic soils within YASSO, which leads to low soil carbon estimates in countries where a large share of the forest grows on peatland (e.g. Ireland). Soil carbon stock increased over time in all test countries, with an annual change of around 0.01 Mg C ha-1 in Finland, Germany, Spain and Sweden, almost 0.3 Mg C ha-1 in Ireland, and 0.8 Mg C ha-1 in Austria. The high increase in Austria was caused by the strong increase in simulated growing stock, which resulted in more litterfall. However, we probably underestimated fellings in Austria, therefore the stock change should be regarded with care.

A step-by-step estimation of uncertainty of the carbon stock estimates of the top-down approach was carried out for Finland, Sweden, Ireland and Spain using Monte Carlo simulation. Sources of uncertainty that were taken into account in the analysis of biomass were inventory data, biomass allocation, dry wood density and carbon content. Simulations of biomass uncertainty were done in two steps: (1) the inventory data was converted into total biomass taking into account the error related to data itself and the error of BEFs; and (2) the total biomass was converted into carbon so that the uncertainty of carbon content was taken into account.

The uncertainty analysis for the stock change from the initial year (1990/1995) to 2010 was done assuming that the data would be based on two inventories – the uncertainty of EFISCEN scenario (i.e. level of thinnings and fellings, no change in forest area and tree species) was excluded from the analysis since we did not have information about its reliability. The uncertainty was calculated in Monte Carlo simulation by calculating the difference between the stocks of the initial year and 2010.

Sources of uncertainty that were taken into account in the analyses of soil carbon were uncertainty estimates of turnover rates and uncertainty estimates of parameters in the soil carbon model.

Biomass C stock uncertainty ranged between 2 and 5%. The uncertainty of the biomass C stock change ranged between 11 and 27%, and was dependent on the size of the change. When the biomass C stock change was low, the uncertainty was higher, while a large C stock change resulted in a lower uncertainty.

C stocks in the soils were much more uncertain than the biomass C stocks, but the C stock change estimate for the soils were more reliable than the soil C stock assessment. The soil C stock uncertainties were very similar between countries – about 45% - because similar assumptions are made in the soil model. Uncertainties in soil C stock changes were highest in Finland (34%) and ranged between 20 and 23% for the other three countries.

The model choice for the soil carbon assessment does also have considerable effect on the results. To study this uncertainty component, a comparison of four different soil carbon models at six selected sites in Finland and Germany was performed, using two different litter input time series as input to the soil models. It was shown that the overall uncertainty due to the selection of the simulation tool for the soil carbon assessment at individual sites may be in the same order of magnitude as the uncertainty due to model parameters. The results of the YASSO carbon stock assessment deviated on average over all 12 investigated litter input/site combinations 19.2% from the average carbon stock calculated by all compared soil models. The deviations occurred in both directions and ranged between 5.0% and 45%. The average deviation of Yasso results from the average annual stock change of all applied soil models was across the investigated 12 litter input/site combinations -16.3%.

2.6. WP7: Bottom-up approach to forest carbon inventories

The bottom-up approach utilizes a multi-phase sampling design that combines different data sources for estimating carbon stock and carbon stock changes. Multi source inventories improve the cost-efficiency of forest resource assessments (Köhl, 1994, Tomppo 2000, Tuominen & Poso, 2001). Within the project consistent and harmonized methods were developed for reliable estimates of carbon stocks and stock changes in European forests. These methods enable to combine available inventory data, remote sensing imagery, and soil carbon observations. Traditional forest inventories provide information on stem volumes, but not on biomass or carbon stock. Thus the available volume estimates had to be converted into biomass and carbon stock estimates by means of biomass functions or biomass expansion factors (BEFs). While BEFs convert existing tree volume estimates into biomass estimates by means of straightforward expansion factors, biomass functions utilize tree measurements such as diameters or tree height as input variables in order to predict tree biomass. The individual components (soil assessments, BEFs, biomass estimation, remote sensing) were studied in test sites representing the major climatic regions in Europe, which allowed to demonstrate the feasibility for operational applications.

2.6.1. Methods

The statistical analysis for the estimation of the carbon stock and carbon stock changes were applied in the four test sites Catalonia in Spain, Salzburg in Austria, Thuringia in Germany and Hyytiälä in Finland. Individual single tree data were made available through bilateral contracts between national data providers and the University of Hamburg. Soil information was provided by WP 3 but could not be merged and up scaled together with the tree information due to different sampling locations. As this is a rather realistic scenario in real applications the estimation procedures for total carbon stock figures were developed under the assumption of lacking spatial coincidence of soil and forest surveys. Methods for expanding volume to biomass were provided by WP2.

Estimates for carbon stock and carbon stock changes are subject to different sources of errors such as sampling errors, assessment errors, classification errors in remote sensing imagery, or prediction errors. Their propagation to the total error was quantified by means of an error budget, which present the contribution of the individual error sources to the total error in terms of variance and bias. Error budgets allow for ranking the error sources according to their contribution to the total error.

Costs and cost efficiency were studied in all test sites. Cost figures obtained from national forest inventories were utilized to quantify the cost for the applied in-situ observations. The objective was to show the gain in precision with respect to assessment cost for each design alternative.

2.6.2. Results

In most cases carbon stocks estimated by applying BEFs are smaller than the carbon stock estimates obtained by biomass functions. Only in some age classes the BEF-based estimates exceeded those obtained by biomass functions. The estimated carbon stocks per hectare are 108 t/ha in the Finish, 151 t/ha in the Spanish, 210 t/ha in the German, and 248 t/ha in the Austrian test site. A carbon stock change estimate was also calculated for the Austrian test site and was found to be 348.909,84 t C per year.

The effect of individual error sources on the minimum reliable estimate of carbon stock and carbon stock changes was studied by means of the error budget as well. Most of the applications of stratification using auxiliary data sources (i.e. EO data) reduced the sampling error remarkably. Post-stratification algorithms also resulted in gains in terms of error reduction. The ranking of the individual error components within the bottom-up approach identified a high influence of the uncertainty of soil carbon stock within the entire carbon stock estimates. Variation in soil carbon stock estimates can cause a percentage root mean square error of more than 27 %. The tree carbon stock estimates proved to be highly accurate with the application of biomass functions, which requires the availability of single tree data; BEFs proved to be suitable for stand wise or aggregated forest information. To study the effect of bias on the total error a sensitivity analysis was conducted. Bias was assumed to be 0,1cm for DBH, 20cm for tree height, -0,02 for tree expansion factors and 20% for soil carbon stock estimates. The bias introduced lead to a percentage root mean square error of more than 35 % in the worst case scenario. The error components of tree measurements like DBH or tree height increased the percentage RMSE by about 5 %. The prediction errors of BEFs and carbon expansion factors (CEF), increased the percentage RMSE by 6,9 % (CEF) and 13 % (BEF). Especially for young spruce trees large RMSE were found.

The application of EO data as stratification source proved to provide the largest gain in efficiency with respect to assessment costs The effect could be shown even for situations where EO data acquisition involved relatively large cost compared to the cost of field assessments. Even where in-situ costs were small EO based stratifications showed a gain in efficiency. The results found for carbon stock estimates hold for the estimation of carbon stock changes as well.

2.6.3. Conclusions

The study showed that combined multi-phase inventory concepts proved to be superior to inventory concepts that utilize only in-situ (terrestrial) data in terms of sampling efficiency. The combined EO/ in-situ approach consistently resulted in smaller sampling errors and thus more reliable carbon stock estimates. The components for carbon modelling (i.e. BEFs, CEF, and biomass functions) were identified to be the most critical error components in estimating carbon stock and carbon stock changes.

Currently BEFs, biomass functions as well as carbon expansion factors were mainly developed for local applications and specific tree species and site conditions. They fail to provide accurate figures for a wide variety of site conditions. In order to increase the reliability further improvement of BEFs, CEF and biomass functions is urgently needed.

2.7. Comparison of top-down and bottom-up approaches

According to the IPCC Good Practice Guidance (IPCC 2003), countries can report their estimates of carbon stock changes for the GHG reporting in different ways. When a country had measured carbon stock at two points in time it can choose to apply a stock-change approach. However, the default method proposed by IPCC is to estimate carbon fluxes for increment (gains) as well as harvest and mortality (losses). Depending on the data basis, time and money available the uncertainty of the reported data can achieve different levels (Tier 1 - 3). Table 2 summarizes different possibilities to calculate carbon stock changes according to the availability of forest inventory and forest statistics data. From the left to the right, data availability, time and cost intensity decreases while the level of uncertainty increases. The lowest uncertainty can be achieved by applying a bottom-up approach to consecutive, permanent inventory data where each year of reporting a representative part of the plots is measured. The highest uncertainty in this table arises from applying a top-down approach to data from only one forest inventory without well-founded data of harvest and mortality. The columns in between these two extreme methods describe intermediate methods in terms of data availability, cost and time efficiency. The uncertainty largely varies depending on the accuracy of the estimates for gross growth, harvest and mortality. The table also indicates that two consecutive inventories can either be applied in a bottom-up approach resulting in a low uncertainty of the carbon stock-change estimates, but they can also be applied more cost effective in a top-down approach causing a higher level of uncertainty.

Table 2: Different methods to calculate carbon stock changes.

	Consecutive inventory for each year of reporting, permanent plots	**Two consecutive inventories, permanent plots**	**Two consecutive inventories without permanent plots**	**One inventory**
Description	Single-tree data to estimate actual forest growth (gains), harvesting and mortality (losses): each year a representative part of the forest is inventoried	Extrapolation of single-tree data	Net stock change derived from the difference in growing stocks (stock_2 – stock_1 = net stock change).	Stock_1 + gross increment – harvesting – mortality = stock_2
Estimation of gains	Derived from single tree data	Growth models or linear extrapolation of inventory data	Gross increment (gains) = Net stock change + harvest + nat. mort.	Gross increment from e.g. yield tables or IPCC default values
Estimation of losses	Derived from single tree data	Growth models or linear extrapolation of inventory data	Harvesting amounts from e.g. forestry statistics Mortality from e.g. expert knowledge or literature	Harvesting amounts from e.g. forestry statistics Mortality from e.g. expert knowledge or literature
Benefits	Very low uncertainty			Not very data intensive
Problems	Very data-, time-, and cost-, intensive	Data-, time-, and cost-, intensive	Level of harvesting and esp. natural mortality difficult to derive (harvesting amounts in private forests are often underestimated or not surveyed	Yield tables often underestimate gross increment, representative yield tables not always available Level of harvesting and esp. natural mortality difficult to estimate (harvesting amounts in private forests often underestimated or not surveyed)
Uncertainty	Very small	Small	Variable depending on the uncertainty of estimates for harvest and mortality	Variable depending on the uncertainty of estimates for gross increment, harvest and mortality
IPCC reporting method	Stock-change approach	Stock-change approach	Mixture between stock-change and default method	Default method
CarboInvent Aggregation level	***Bottom-up***	***Bottom-up or top-down***	***Top-down***	***Top-down***
Methods tested in the report	Combined 2 phase multi source inventory for carbon stock changes on plot level (WP7)		Stock change method applied in the top-down approach, but no estimates for increment and drain (WP6)	EFISCEN model projections are presented as one special case of this approach (WP6)

2.7.1. Methods

Forest inventory data and the biomass functions gathered and developed during the CarboInvent project were integrated in two ways: in a top-down approach (WP 6) using aggregated inventory data, and in a bottom-up approach using inventory data at the plot level (WP 7). We compared biomass allocation and tree carbon stocks of the bottom-up and top-down approaches for the test regions located in Austria (Salzburg), Finland (Hyytiälä) and Germany (Thuringia). In the bottom-up approach, biomass functions were applied directly to the dimensions of the inventoried trees, mostly diameter and height, and then age- and tree species-specific carbon estimates were calculated. The single tree results were aggregated by tree species and age class.

In the top-down approach, no single tree dimensions were available, only aggregated information from the inventory. Growth and yield tables were used in order to assign diameter and height to the age class information of the forest inventory data. Only for the Finnish test region, biomass allocation could be derived directly from the applied biomass functions.

The same biomass functions were used in both approaches for the test regions in Austria and Germany. For the Finnish test region, tree compartment-specific biomass functions were used in the top-down approach, while the bottom-up approach used functions from the same literature source that expanded to total tree biomass directly, or only aboveground biomass in the case of broadleaves. Total tree carbon stocks differed only slightly (1-2%) in the Austrian and German test regions, where the same biomass functions were used in both the bottom-up and the top-down approach. In the Finnish test region, the deviation was 6%. Additionally, for one of the test regions (Thuringia) we compared the share of each biomass compartment calculated for both approaches. We also assessed the effect of using different growth and yield tables for spruce (Thuringia).

2.7.2. Results

Our comparisons showed that the deviation between the bottom-up and top-down approach was highest for the youngest age classes and leveled off with increasing age. Since the carbon stock is still very low in young stands, the difference in biomass allocation and carbon stocks in young stands between the two approaches had only a small effect when comparing the carbon stock for the total test regions.

Carbon stock changes were calculated for the Austrian test region, Salzburg, because data from two consecutive inventories was available. The annual carbon stock change varied only slightly between the two approaches: 0.74 Mg C ha^{-1} yr^{-1} for the bottom-up approach, and 0.76 Mg C ha^{-1} yr^{-1} in the top-down approach. The carbon stock change projected by EFISCEN for the same period was with 1.45 Mg C ha^{-1} yr^{-1} almost twice as high, mainly due to underestimated harvest levels in the applied FAO data and high increment rates assumed in the model.

The two carbon assessment methods developed in WP6 and WP7 of CarboInvent can be seen as extreme examples from a range of possible methods for reporting under the UNFCCC and the Kyoto protocol in terms of demand on data availability, cost and time efficiency. The bottom-up approach as presented in WP7 results in the lowest uncertainties in the results, but it depends on detailed forest inventory data for each reporting year.

The top-down approach offers a very cost-efficient method for assessing stock changes in situations where no repeated inventories are available. However, the projection of carbon stocks with the modeling framework is sensitive to the accuracy of the available harvest and increment estimates. When new inventory data become available, a recalculation of the carbon stocks and stock changes is advisable to remove the error source from uncertain flux estimates. According to the Good Practice Guidance it is good practice to recalculate all earlier estimates when better information is becoming available. This means that countries could base their reporting on the application of the top-down method with some simple extrapolation of previous inventory results (or EFISCEN projections) and recalculate the reported results once the next inventory results become available with a second application of the top-down or bottom-up approach directly to the inventory data. Uncertainties can generally be reduced, if no extrapolation method is needed. Therefore it is beneficial for countries with regular forest inventory cycles to measure each year a representative fraction of all inventory plots.

2.7.3. Conclusions

Probably, many countries will report their carbon stock-change estimates with a derivate of the top-down approach. If a country has only one inventory, it might be more cost effective to spend time and money in assessing gross increment, harvesting amount and mortality than to conduct an entire second national forest inventory. This approach then corresponds with the IPCC default method. Therefore, further investigations should be done related to carbon stock changes calculated with the top-down method based on one inventory and additional knowledge about increment, harvest and mortality. One crucial question in this context is how can the uncertainty of stock-change estimates be decreased by increasing the accuracy of the estimate of increment, harvest and mortality.

3. WP8: Kyoto Protocol carbon budgets

WP 8 concentrated its activities on integration of various data and methodological approaches in order to enable preparation of GHG inventories for LULUCF according to requirements of the Kyoto Protocol (KP). As a result the KP entering into force, Parties to the KP must *inter alia* report on:

Identification of values for tree crown cover, land area and tree height for use in accounting for activities under Art. 3.3 and 3.4.	Required by Art. 3.3 and Art. 3.4 of the KP and Paragraphs 1 and 16 of the annex to draft decision -/CMP.1 (Land use, lans use change and forestry) a contained in text B of document FCCC/KP/CMP/2005/3/Add.1.
Election of activities under Art. 3.4 for accounting in the first commitment period	Required by Art. 3.4 of the KP and Paragraphs 6-12 of the annex to draft decision -/CMP.1 (Land use, land use change and forestry) a contained in text B of document FCCC/KP/CMP/2005/3/Add.1.
Identification of the accounting period for each activity	Required by Art. 3.4 of the KP and Paragraphs 25 and 32 of the annex to draft decision -/CMP.1 (Land use, land use change and forestry) a contained in text B of document FCCC/KP/CMP/2005/3/Add.1.
Supplementary inventory information for activities under Art. 3.4 and 3.4.	Required by draft decision -/CMP.1 (Good practice guidance for land use, land use change and forestry activities under Article 3.3 and 3.4 of the Kyto Protocol) as contained in text C of document FCCC/KP/CMP/2005/3/Add.1, and Chapter I, section D, of the annex to draft decision -/CMP.1 (Article 7).

Taking into account the above requirements, CarboInvent Partners cooperating within the WP 8 provided guidance and information on the following issues.

3.1.1. Workshop "Land-use Related Choices under the Kyoto Protocol Obligations, Options and Methodologies for Defining Forest and Selecting Activities under Kyoto Protocol Article 3.4"

As a result the Protocol entering into force, Parties to the KP must adopt a single definition of the term *forest* and elect any or all of the following human-induced activities under Article 3.4 in the first commitment period: revegetation (RV), forest management (FM), cropland management (CM), and grazing land management (GM). KP and subsequent decisions in the Marrakech Accords (MA) provide a rather broad definition of FM and wide ranges for selection of national thresholds in the definition of forest. Arriving at the right definitional choices requires consideration of:

- carbon benefits and their uncertainty ranges resulting from the adopted definition of forest and from the adoption of each Art. 3.4 activity;
- risk of potential need to report carbon liabilities as a result of the adoption of each Art. 3.4 activity,
- cost of monitoring/data collection and reporting,
- trade-offs and synergies with other national objectives, such as environmental or socio-economic.

In order to present the current state of scientific understanding, requirements within the KP, environmental integrity, practical applicability and cost effectiveness of the above mentioned decisions a workshop “Land-use Related Choices under the Kyoto Protocol Obligations, Options and Methodologies for Defining Forest and Selecting Activities under Kyoto Protocol Article 3.4” was organized by Joanneum Research (with FAO, CarboEurope, INSEA and COST as co-organizers), in Graz / Austria in May, 2005. The workshop was targeted at policy and decision makers on KP issues related to LULUCF and staff of national agencies working on GHG reporting under the UNFCCC and the KP in Annex I countries, and attracted 71 attendees from 22 countries located on 5 continents.

The plenary and parallel session of presentations provided an excellent overview of the current state of knowledge and background for discussion and exchange of experience and information. The sessions included input from the following CarboInvent Partners: Joanneum Research, Joint Research Centre, Institute of Forest Ecosystem Research, Hungarian Forest Research Institute, Swedish University of Agricultural Science and University of Padua. As a result, the workshop break-out groups produced valuable conclusions and output. All reports and presentations as well as a comprehensive selection of background documents are available through the project website: http://www.joanneum.at/carboinvent/workshop/workshop02.html.

3.1.2. Data requirements specific to the Kyoto Protocol

When definitional issues are settled, the next steps are collecting data and reporting under KP. A piece of land enters the reporting procedures under the KP Art. 3.3, as a result of change in forest area (afforestation - A, reforestation - R and deforestation - D) while, under Art. 3.4 the changes in carbon pools over forest (FM) or non-forest (CM; GM and RV) areas are reported. Although (under the Art. 3.3) entering of a unit of land into the KP reporting system results from change in land use from non-forest to forest or vice versa, the reporting requirements under the LULUCF significantly depend on direction of the change. If a change is from non-forest to forest (A/R) then the land area enters the continuous reporting paradigm under the LULUCF. If the direction of change is from forest to non-forest (D) then the reporting under the LULUCF is limited to a single event (GHG emission due to deforestation) while subsequent reporting is performed under the particular land use. Hence, methodological approach to reporting is different in these two cases. In the case of AR activities, the main issues are: an extension of the NFI to collect data (especially for small trees) and approach to convert the data into estimates of biomass and carbon pools, while, area of the newly established forest is usually known. In the case of D activities the data on forest are available if size and location of the deforested area are known hence, the methodological issue is detection of deforestation events (area, location). The negative impact on national GHG inventory and possibly illegal character of the D activities requires detection procedures which are independent from ownership of forest.

Two studies on identification of data requirements for fulfilment of Kyoto Protocol (KP) reporting of A/R/D activities on a national/regional scale according to the Good Practice Guidance for reporting Land Use Land Use Change and Forestry (GPG LULUCF) were prepared by Joanneum Research and the Hungarian Forest Research Institute. The studies reviewed KP reporting process and identified existing national data sources that could be utilised reporting to the KP as well as important information gaps.

3.1.3. Developing methods to calculate elements of the KP GHG inventories

As the next step, a couple of efforts were made to calculate elements of the KP GHG inventories were undertaken. This resulted in estimation of KP GHG inventories for A/R activities reportable under Article 3.3 or joint implementation projects as well as an assessment of error range in estimation of D area using data from NFI sample plots and a trial of establishing the GHG inventory for revegetation treated as activity under the Art. 3.4 of the KP.

A case study approach to Kyoto Carbon Budgets for Afforestation Activities was performed by National University of Ireland (CarboInvent Partner 4). The study revealed that the data used for reporting to the UNFCCC resulted from assessments of public forests, providing data on potential maximum annual increment (yield class - YC). Data from the private sector was not available and that from the public sector is not readily transferable as species composition and management practices generally differ significantly. In Ireland, the majority (76%) of post 1990 forests eligible for reporting under Article 3.3 of the KP are privately owned hence, a large uncertainty would have to be associated with any estimate developed from the application of such information because the YC and subsequent volume models are based on trees of merchantable timber volume (i.e. with diameter at breast height (DBH) exceeding 7 cm). The majority of post 1990 forests eligible for reporting during the first commitment period would be below this minimum size requirement for applicability. Therefore other stock estimation options, such as the use of nationally specific biomass functions, were considered more reliable.

The most significant national outcomes in Ireland arising during the course of the CarboInvent project included changes the NFI data collection regime, which was altered to include measurements of trees below 7cm DBH. In order to enable reporting of the five major forest pools (i.e. above- and belowground biomass, soil organic carbon, litter and deadwood), as specified in the GPG LULUCF, the NFI design phase also included data collection for use in the development of stock estimates for other forest carbon pools. Parameters recorded include soil type, the presence and depth of a litter layer and the presence of deadwood, its decay rate, and volume estimates.

A comparison of C stocks for the five specified pools and associated uncertainties was made between the three reporting tiers. This allowed an analysis of specific gaps in the ability of Ireland to report to the highest Tier for each pool. The study proved that totals in the GHG inventory for LULUCF are most sensitive to parameters used in the development of estimates in the Living Biomass and Soil Organic Carbon pools.

A separate study performed by Hungarian Forest Research Institute/Joint Research Centre and Institute of Forest Ecosystem Research was aimed at providing guidelines and improved standards for monitoring and verification of carbon removals in afforestation/reforestation joint implementation projects. The study was aimed at establishment of the full budget of relevant GHGs in a hypothetical A/R joint implementation project in Hungary. The country was selected because of possible interest in locating A/R JI activities in newly accessed EU countries.

The project identified data needs for reporting and offered an exemplary report covering all greenhouse gas emissions and removals which have to be monitored according to provisions of the Kyoto Protocol and the Marrakesh Accords. Carbon stock changes in all but dead wood carbon pools were estimated (but carbon stock changes in all pools were reported, using appropriate assumptions). NFI data was used to estimate aboveground biomass carbon stocks and their changes by means of site specific factors that were developed in the study. The biomass campaign was also used to develop biomass equations to model and analyze situations where the equations allow arriving at more accurate estimates. The belowground biomass, and its changes, were estimated using default factors. However, soil and litter carbon stock changes were estimated using site-specific data. In order to develop carbon stock change data for a period of five years, i.e. longer than the duration of the CarboInvent project, the advanced version of the CASMOFOR model was developed and used. In addition to the emission and removal estimates, a complete uncertainty analysis was carried out. As a final step of the study, detailed guidelines were proposed to improve application of GPG LULUCF approach for estimation of greenhouse gas emissions and removals in monitoring of afforestation/reforestation projects.

Another study prepared by University of Padua was aimed at the potential role of revegetation (RV) in Mediterranean countries in context of their GHG reduction commitments during the first commitment period under the KP and consequently provide suggestions whether election of RV could be beneficial for those countries. Hence, the C benefits resulting from RV activities were compared to cost of development of inventory and monitoring systems able to identify lands subjected to RV and estimate C stocks and emissions and removals of GHGs.

The first step was to provide a better definition of RV activities, based on identification of national criteria which are based on political decisions and strongly influence the RV significance at the country level. In fact, RV is a buffer activity between the other activities of art. 3.3 (A/R) and of art. 3.4 (CM, GM) of the KP and data associated with RV is usually not monitored within the NFIs nor in national land-use databases.

The study revealed that RV may be significant only if the definition of RV is based on a ‘broad’ approach, where a country would define a system of RV practices without specifying each RV practice that has taken place on each piece of land. In particular a broad definition of human-induced activities may include the expansion of vegetation on former agricultural lands under AR or RV depending on whether the land-use change leads to the development of a forest or not, under the KP forest definition. Other RV activities seem to be not relevant. Actually the development of green urban areas would unlikely lead to significant GHG removals due to the limited area affected. The same applies to linear plantations; moreover, it must be added that the permanence of the latter depends habitually on the existence of public funds: without them, in fact, it is usually not cost effective for farmers to preserve the subsistence of linear plantations.

Another study performed by Joanneum Research was aimed at methodological problem of detection small ARD events and estimation of their area using NFI approach based exclusively on a net of sample plots. The NFIs are the most detailed national sources for information on forests. They have been a basic source of numerical information used in preparation of the GHG inventories since beginning of the UNFCCC process. Good Practice Guidance for LULUCF confirms that the use of NFI as a source of information is a “good practice” in the GHG inventory preparation, both for the purposes of UNFCCC and the Kyoto Protocol reporting. This includes detection of ARD events.

In Annex I countries, the forested land and ARD represent areal events, which significantly differ in size (by couple of orders of magnitude). Hence, estimates of area for forest and ARD events obtained from the NFI differ in precision and applicability in the context of Kyoto Protocol.

The theoretical analysis and Monte Carlo type model were developed and applied for testing sensitivity of the NFI geometrical arrangement to the presence of ARD events. The theoretical analysis showed that detectability of ARD events much smaller than the NFI grid depends not only on their area but also on their shape and geometrical arrangement of sample plots within the NFI grid. The analysis was continued with a model approach which mirrors geometrical arrangement of the NFI based on circular sampling plots. The simulation was performed for ARD events with fixed area ranging from 0.1 ha to 50.0 ha. The results proved that the NFI tends to overestimate areas of the events much smaller than a size of the NFI grid. The relative overestimation increases with decreasing area of ARD event. It is important to note that the above result applies only for ARD events which are smaller than the NFI grid hence, it does not pertain to typical application of the NFI over areal objects much larger than the grid size.

Concluding, the WP8 of the CarboInvent significantly contributed to better understanding of definitional issues relating to the KP and their consequences, defined data requirements posed by the KP and Marrakesh Accords, addressed reporting of ARD under the KP both at country and at project level, and discussed and developed methodological issues rising from the KP requirements. The obtained results, although based on country specific test sites, are applicable to the majority of the EU countries.

3.1.4. Conclusions

The WP8 of the CarboInvent significantly contributed to

- Better understanding of definitional issues relating to the KP and their consequences,
- Practical guidance on national choices under Art. 3.3 and 3.4 of the KP,
- Definition of data requirements posed by the KP and Marrakesh Accords,
- Practical expertise on reporting of ARD under the KP both at national, as well as at project level, and
- Discussion on methodological issues arising from the KP requirements.

The obtained results, although based on country specific test sites, are applicable to majority of the EU countries.

4. Final achievements and conclusions

- The existing knowledge on biomass equations and biomass expansion factors was compiled and made it easily available for the users by systematizing it in publicly available database and scientific publications.

- Terms and definitions used in the biomass estimation were further developed and rules for their use were clarified

- Guidance on use of indirect methods to estimate forest biomass has been provided, what will facilitate harmonization of the European inventories of forest biomass.

- Selected methods applicable for biomass and carbon inventories were tested with aim to improve quality and consistency of the biomass and carbon inventories in the European countries.

- Application of Remote Sensing to the test sites demonstrated, that RS methods can optimally complement already available data from national forest inventories for large area assessment of carbon stocks and stock changes. Whereas national forest inventory data is in general only available for small sample plots, the remote sensing methods allow a wall to wall mapping (full aerial coverage) of forest parameters, especially stem volume, tree biomass and carbon stocks.

- In order to improve estimation of carbon stocks and stock changes at the national level, the remote sensing classification results were used for stratification aiming at reduction of the sampling error of the estimates (e.g. in bottom up approach).

- The methodical framework has been developed to optimize large scale national forest soil inventories for detection change in soil organic carbon stocks. This enabled to find that refined error tracking is needed before the time frame and sample density can be determined.

- Detection of the change in soil organic carbon stocks strongly depends on the statistical sample error, which likely underestimates the real uncertainties hence, is of systematic nature. Hence, changes in soil C are difficult to detect if they are not related to land use change. But even then, the changes may be statistically insignificant. Applicability of the existing national soil inventories for SOC detection is limited because:

    - litter sampling is lacking or insufficient

    - number of subsamples per plot is insufficient, especially for the litter layer

    - information about present and historical forest management and disturbances is limited

    - soil bulk density is rarely measured

    - stones are only visually assessed without calibration on the basis of measurements

    - analytical conversion and recovery factors are frequently subjected to methodological deficiencies

    - systematic inventory systems have typically representativity gaps (especially in regions with fragmented forest distribution)

- Considering a predicted SOC change of ca. 50 kg/ha/year under managed forest in central Europe, and considering that an unbiased soil survey was conducted (after careful representativity analysis and elimination of main systematic errors), the statistical detectability of change of the regional soil carbon stock with such an inventory is ca. 40 years. Some inventory modifications (such as higher precision of the plot georeferencing) and the availability of higher resolution maps such as climate and soils, may further improve the accuracy of soil inventory-derived SOC change assessments.

- The methodological work resulted in definition of a need to improve assessments of influence of the major stand replacing events on carbon emissions and removals through better detection of area of lands subject to the event as well as through including dynamic effect of change in age class structure and in harvesting regime. In order to allow for it:

    - a proposal for restriction of monitored disturbances to major stand replacing events was elaborated,

    - methods available for the monitoring of the effects of these disturbance events were reviewed and ways to complement standard inventories for this purpose were proposed ,

    - coarse woody debris was identified as an important carbon pool and a data base on decay constants was compiled,

- the bottom-up approach was applied utilising a multi-phase sampling design that combines different data sources for estimating carbon stock and carbon stock changes. The current BEFs, biomass functions and carbon expansion factors were successfully applied on single tree data and upscaled using the most current algorithms, including utilisation of EO data for stratification purposes. The application of EO data into the stratification procedures provided the largest gain in efficiency with respect to assessment cost.

- The results of the bottom up approach are among the most reliable carbon stock and carbon stock change estimates achieved in test sites representing the major climatic regions in Europe.

- error budgets were set together what allowed ranking the different data sources and algorithm errors according to their contribution to the total error. The components for carbon modelling (i.e. BEFS, CEF, and biomass functions) were identified to be the most critical error components in estimating carbon stock and carbon stock changes. For increment of the reliability further improvement of BEFs, CEF and biomass functions is needed also in terms of local adaptation methods with respect to site conditions.

- The result of multi phase combined carbon inventories contributed to improvement of the reliability of carbon stock and carbon stock change estimates for the yearly reporting periods, including direct integration of soil carbon estimates
- Large-scale forest scenario model, EFISCEN in combination with a dynamic soil model, YASSO and Monte Carlo simulation were used to assess uncertainties in carbon stocks and carbon stock changes. Uncertainty of carbon stock in biomass ranged between 2 and 5%. The uncertainty of change in the biomass carbon stock ranged between 11 and 27%, and was dependent on the size of the change. When the biomass C stock change was low, the uncertainty was higher, while a large C stock change resulted in a lower uncertainty.

- Uncertainties in carbon stocks in soil (ca. 45%) were greater than those in the biomass C stocks. On the other hand, uncertainties in soil C stock changes were smaller than those in carbon stocks in soils with the highest values for Finland (34%) and between 20 and 23% for the other three countries.

- Currently, majority of the European countries report changes in carbon stocks (under the UNFCCC requirements) using variants of the top-down approach, which corresponds to the IPCC default method. Hence, further efforts are needed to improve accuracy stock-change estimates by increasing the accuracy of the estimate of increment, harvest and mortality. The bottom up approach is still in “laboratory” phase however, its wide-scale application will follow a need to use Tier 3 approaches in a case of KP reporting for key categories in LULUCF.

- A workshop “Land-use Related Choices under the Kyoto Protocol Obligations, Options and Methodologies for Defining Forest and Selecting Activities under Kyoto Protocol Article 3.4”, was organized by Joanneum Research (with FAO, CarboEurope, INSEA and COST as co-organizers), in May, 2005. The workshop was targeted at policy and decision makers on KP issues related to LULUCF and staff of national agencies working on GHG reporting under the UNFCCC and the KP in Annex I countries. It dealt with the current state of scientific understanding, requirements within the KP, environmental integrity, practical applicability and cost effectiveness of the LULUCF definitional choices required by KP. The workshop attracted 71 attendees from 22 countries located on 5 continents.

- A review of the KP reporting process and identification of existing national data sources that could be utilised in reporting to the KP enabled to define possible information gaps. Those were identified mostly in detection of small ARD events and estimation of changes in the soil organic carbon pool.

- Reporting on carbon stock changes resulting from AR activities performed under Art. 3.4 or within the JI scheme was tested on full scale areas in Ireland and Hungary. The effort enabled to define AR specific data gaps and resulted in proposal for extension of the NFI to the KP specific issues and practical assessment as well as suggestion of improvements in application of the GPG LULUCF.

5. Publications resulting from the Project

N°	Title/Topic	Proposing person	WP	Journal	Year
1	Indirect methods of estimating forest biomass	Somogyi, Z., Cienciala, E., Mäkipää, R., Lehtonen, A., Muukkonen, P. & Weiss, P.	2	European Journal of Forest Research (Submitted)	2005
2	Differences among species in aboveground biomass expansion factors in Mediterranean forests.	Sabate, S., Gracia, C.A., Vayreda, J., Ibáñez, J.	2	Forest Ecology and Management in revision.	2005
3	Biomass and stem volume equations for tree species in Europe.	Zianis, D., Muukkonen, P., Mäkipää, R. & Mencuccini, M.	2	Silva Fennica Monographs 4: 1-63.	2005
4	New simplified regressions for volume and biomass for some European tree species.	Muukkonen, P.	2	European Journal of Forest Research	Revision submitted. 2006
5	The relationship between biomass and percentage cover in understorey vegetation of boreal coniferous forests.	Muukkonen, P., Mäkipää, R., Laiho, R., Minkkinen, K., Vasander, H. & Finér, L.	2	European Journal of Forest Research	in revision. 2006
6	Biomass expansion factors for Norway spruce in Czech Republic with uncertainty estimation.	Lehtonen A, Cienciala E, Tatarinov F, Mäkipää R and Černý M	2	Manuscript considered for publication	2006
7	Carbon stocks and flows in forest ecosystems based on forest inventory data.	Lehtonen, A.	2	Dissertationes Forestales 11: 1-51.	2005
8	Estimation of biomass stock of trees in Sweden: comparison of biomass equations and age-dependent biomass expansion factors.	Jalkanen, A., Mäkipää, R., Ståhl, G., Lehtonen, A. & Petersson, H.	2	Annals of Forest Science 62(8): 845–851.	2005
9	Estimating foliage biomass for Scots pine (Pinus	Lehtonen, A.	2	Tree Physiology	2005

	sylvestris L.) and Norway spruce (Picea abies (L.) Karst.) plots.			25(7): 803-811.	
10	Biomass expansion factors (BEF) for Scots pine, Norway spruce and birch according to stand age for boreal forests. Forest Ecology and Management 188, 211-224.	Lehtonen, A., Mäkipää, R., Heikkinen, J., Sievänen, R., Liski, J.,	2	Forest Ecology and Management 188, 211-224.	2004.
11	Carbon sink of the Finnish forests 1922–2004 estimated by combining forest inventory data with modeling of biomass, litter and soil.	Liski, J., Lehtonen, A., Palosuo, T., Peltoniemi, M., Eggers, T., Muukkonen, P. & Mäkipää, R	2	European Journal of Forest Research	Submitted manuscript.
12	Biomass equations for Austria	Weiss P (editor)	2	Special Issue of: Austrian J. Forest Res.	2005
13	Above- and belowground biomass measurements in an unthinned stand of Sitka spruce (*Picea sitchensis* (Bong.) Carr.)	Green C, Tobin B, O'Shea M, Farrell EP and Byrne KA	2	European Journal of Forest Research	Accepted
14	Tree and understorey biomass estimates in young managed mixed conifer plantations afforested on blanket peatland	Green C, Tobin B, Nieuwanhuis M and Farrell EP	2	In prep	2006
15	Age dependent BEFs for beech and spruce in temperate forest	Cienciala E et al.	2	Open	2006
16	Error propagation from sample plot to landscape	Jandl R et al.	3	Open	2006
17	Soil and Forest Floor Organic Carbon Stocks in a Chronosequence of Sitka spruce	Green C, Saiz G, Avitabile V, Farrell EP and Byrne KA	3	Forest Ecology and Management	Submitted
18	Seasonal and spatial variability of soil respiration in a Sitka spruce chronosequence.	Saiz G, Green C, Butterbach-Bahl K, Kiese R, Avitabile V, Farrell EP	3	Plant and Soil	Submitted
19	Estimating the soil C pool from site data	Jandl R et al.	3	Austrian Journal of	2006

				Forest Research	
20	Methodological standards to detect forest soil carbon stocks and stock changes at landscape scales	Baritz, R. et al.	3	open	2006
21	Upscaling forest soil monitoring data – scale and representativity effects	D. Zirlewagen, R. Baritz and K. v. Wilpert	3	open	2006
22	The role of soil inventories for the ecosystem-based assessment of the greenhouse gas balance of forests	R. Baritz, C. Green, R. Jandl, M. Lindner, M. Mund, M. Olsson, J. Romanya, P. Rovira, G. Saiz, G. Matteucci	3	open	2006
23	Requirements and frame conditions to consider soil carbon and litter in greenhouse gas reporting	R. Baritz, W. Galinski, Z. Somogyi, M. Lindner, E. Thuerig	3	open	2006
24	Assessment of forest stand parameters from laserscanner data in mixed forests.	Wack R & H.Stelzl	4	FINSAT	2005
25	Estimation of woody biomass at the regional level by means of remote sensing methods	Gallaun H. et al.	4	open	2006
26	Mapping woody biomass and carbon stocks by means of combined field and remote sensing methods	Gallaun H. et al.	4	open	2006
27	Area frame sampling with very high resolution remote sensing imaging for monitoring land cover changes	Gallaun H. et al.	4	open	2006
28	Steigendes klimatisches Waldbrand risiko in Brandenburg	Badeck F et al.	5	AFZ	2004
29	Estimation of decay constants for European tree species from literature sources	Rock J, Badeck F	5	open	2006
30	Suitability of published	Rock J	5/2	Biomass and	2006

	biomass equation for aspen in Central Europe			Bioenergy	
31	Aboveground Biomass – dynamics after windthrow in boreal forest	Rock J et al.	5	open	2006
32	Relevance of substitution for total climate effect of wood use	Fürstenau et al.	5	open	2006
33	Forest management options and their influence on different C stocks in forest at different levels of aggregation	Rock J et al.	div.	open	2006
34	Forest resource development in Europe under changing climate and land use.	Meyer J, M. Lindner, S. Zudin, J. Liski, S. Zaehle	6	Global Change Biology	2006
35	Comparing forest inventory based carbon stock assessments for three regional cases using plot level and aggregated inventory data.	Meyer J, E. Thürig, B. Kenter, M. Lindner, M. Köhl	6	Forest Ecology and Management	2006
36	Soil carbon stocks and stock changes simulated with four soil models - what can we learn from different model results?	Faubert P, M. Lindner, E. Thürig, M. Peltoniemi, T. Palosuo, O. Chertov, A. Komarov, A. Mikhailov, F. Suckow, P. Lasch, M. Wattenbach, P. Smith, P. Gottschalk, J. Liski	6	open	2006
37	Uncertainties of alternative forest inventory based carbon stock assessments	Vilen T., B Kenter, M. Peltoniemi, E. Thuerig, J. Meyer, M. Lindner	6	open	2006
38	Accuracy estimate of BEFs and Biomass functions in Austrian test site		7	open	2006
39	Comparison of standwise	Wirth et al.	7	open	2006

	and sampling plot				
40	Experiences of testing GPG methodology in AR JI projects	Somogyi Z.	8	Climate Change Policy	2005
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