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Research activities related to the role of forests and forestry in climate change mitigation in Austria

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Forests and forestry play important roles in Austria with its close to 50% forest cover. This paper provides details about the Austrian forest carbon inventory, discusses briefly the sources and sinks accounted under the LULUCF Articles of the Kyoto Protocol, and presents an integrated carbon model (ACBM) that was developed to include not only the forest sector, but also other sectors that are greenhouse-gas relevant. Improvements in forest management practices are seen as important possibilities of increasing the carbon sink strength of Austrian forests, but also of pursuing other goals such as increased biodiversity and resistance to future climate-change impacts. This paper concludes by presenting a process model and a carbon accounting model that are applicable for evaluating carbon impacts of changes in forest management.
Keywords. Forest carbon inventory, forest management, carbon balance, carbon stocks, carbon fluxes, full carbon accounting, tree growth, Austria.

1. INTRODUCTION

Data on the Austrian Greenhouse Gas (GHG) emissions, which are submitted to the United Nations Framework Convention on Climate Change (UNFCCC), are calculated annually by the Federal Environment Agency. The underlying energy source data are derived from the energy balances, which are provided on an annual basis by the Austrian Institute for Economic Research (WIFO, 1996) and by the Central Statistical Office (ÖSTAT) for 1996–1998. The format and compilation of the reported GHG emissions correspond to the recommendations for inventories set out in the "Revised Guidelines for the Preparation of National Communications by Parties Included in Annex I to the Convention" and in the "IPCC 1996 Guidelines for National Greenhouse Gas Inventories". Austria, as many other European countries, uses the CORINAIR calculation method for quantifying national emissions. Due to updated calculation methods, the last Austrian submission to UNFCCC (April 2000) included revised data for the whole period 1980 to 1997 and the actual figures for 1998: in the period 1990 to 1998 the Austrian gross CO_2 emissions were between 59.9 and 66.8 $Tg \cdot y^{-1}$. In the same period between 459 and 538 Gg $CH_4 \cdot y^{-1}$ and between 6.56 and 7.41 Gg $N_2O \cdot y^{-1}$ were emitted in Austria. The Austrian emissions of HFCs, PFCs and SF6 were negligible (Ritter, 1999). In the period 1990 to 1996 the sector 5A ("changes in forest and other woody biomass stocks", which partly includes sector 5B "forest and grassland conversion" and sector 5C "abandonment of managed lands") represented a net CO_2 sink (the submitted data are presented in § 2.1). Data on sector 5D ("CO_2 emissions and removals from soils") and on sector 5E ("Other") were not reported so far.

2. WORKING GROUP 1 RELATED ACTIVITIES (Inventory of C sinks and sources)

2.1. The carbon balance of the Austrian forests 1961–1996

About 50% of Austria is covered by forests (FBVA, 1997). First estimates by Körner *et al.* (1993) showed that the forests constitute an important share in the carbon stock of the Austrian landscape. Jonas (1997) provided data on the net carbon sink of the Austrian forests. Based on the experiences of these studies and new literature data a project was started by the Federal Environment Agency in collaboration with the Federal Forest Research Center with the following main objectives:

- calculation of the annual carbon balance of the biomass in Austrian forests between 1961 and 1996,
- calculation of the carbon stock of the Austrian forests in 1990,
- analysis of the uncertainty of these data,
- estimate of the change in the forest soil C pool between 1961 and 1996, and
- estimate of the possible C source or sink under Kyoto Protocol Art. 3.3 (Weiss *et al.*, 2000).

The main basis of these calculations were measured data on forest area, increment, harvest and stock of stemwood (> 5 cm dbh) according to the Austrian National Forest Inventory (NFI) which are given in Schieler *et al.* (1995) and FBVA (1997). The NFIs were carried out in the periods 1961 to 1970, 1971 to 1980, 1981 to 1985, 1986 to 1990 and 1992 to 1996. Since 1981 the NFI uses a 4 × 4 km grid with four permanent sample plots of 300 m^2 size at each grid point. The mean annual increments and harvests according to NFI were converted with indices which were derived from national statistics and literature data (Bittermann, Gerhold, 1995; BMLF, 1964–1998, Hasenauer *et al.*, 1999) to annual data of increment and harvest (instead of using the means of inventory periods or interpolated values for single years). These data were converted and expanded to tC increment and tC harvest of the whole trees by conversion factors. These factors were derived from a comprehensive literature survey and calculated separately according to the species and age class composition of increment and harvest (and stock in 1990).

The C-stock of the Austrian forest soils was calculated by using data of the Austrian forest soil survey: 8.7 × 8.7 km grid across all Austria (FBVA, 1992). No repetition of this survey has taken place, so simplified modelling approaches were used to estimate the C stock change of the Austrian forest soils in the period 1961 to 1996. In order to reduce the uncertainty related to decomposition times of organic matter and turn-over times of soil C, only the net changes of C fluxes to and from the forest soils in this period were used for these estimates. With respect to these net changes, the increase of the Austrian forest area, the changing management practices, the increase in litter-fall and temperature changes (+0.5°C during the period 1961–1996) etc. were taken into consideration.

The uncertainty of the C balance of the Austrian forest biomass was calculated by including the statistical uncertainty of the forest inventory, the uncertainty related to the calculation of annual data[1], the uncertainty related to the missing consistency of different statistics (e.g. for annual harvest, see also § 2.3) and the uncertainty of each conversion and expansion factor. The uncertainties of the conversion factors were estimated in a pragmatic and conservative way (e.g. by using standard deviations instead of standard errors when calculating the uncertainties of the conversion factors). Such a procedure should take into account that the conversion factors were not measured by a systematic inventory (like NFI) but derived from few and local ecosystem studies and other literature. The error propagation was used to calculate the overall uncertainty (details of the approach can be found in Weiss *et al.*, 2000).

In 1990 the Austrian forests (3.9 Mha) represented a C-stock of 320 ± 42 Mt C (biomass) and 463 ± 185 Mt C (soil). In the period 1961 to 1996 the Austrian forest biomass was each year an annual net C sink of between 1,014 kt C and 3,689 kt C (mean 2,527; uncertainty ± 748 kt C). It was estimated that the Austrian forest soils were also a net C sink (of about 10 % of the net C sink of the forest biomass) in this period. However, this result has to be considered hypothetical, and cannot be substituted for measurements of the changes in this important C pool. Like in most other countries, Austrian Kyoto Article 3.3 lands might be a relatively small C sink or source in 2008 to 2012; this will depend on the definitions, scenarios and accounting rules. These data are available at the UNFCCC homepage, on line at: <http://www.unfccc.de/resource/docs/2000/sbsta/09a1.pdf>.

For further information on the contents of § 2.1 please contact Peter Weiss: weissp@ubavie.gv.at.

2.2. The ACBM Model

The main goal of the "Austrian C-Balance Model" (ACBM) is to establish a dynamic model that reflects the dynamic behaviour of the carbon cycle in Austria. It includes all relevant national carbon reservoirs and fluxes in Austria. The model simulates the fluxes and reservoirs of carbon for two scenarios "No Major Changes" and "Towards Sustainability" for 1990 to 2010 (Orthofer *et al.*, 1999). The "No Major Changes" scenario refers to the most likely development in light of current economical, societal, and technical development. The "Towards Sustainability" scenario reflects a more pronounced trend towards more environmental awareness and its implications in public attitude, consumption patterns and economical development.

The project is based on the methodology of a calculation of the 1990 carbon balance in Austria (Orthofer, 1997; Jonas, 1997). The methodology focuses on the development of a "full" national C-balance. The national "full" balance that takes into account all sources and sinks within a country allows to understand a national carbon flux system, thus enabling scientists and policy makers to establish and implement policies for reducing carbon release into the atmosphere.

The overall carbon cycle in Austria is disaggregated into five carbon modules which correspond largely to the sectors defined by IPCC (1996): agriculture, energy transformation and use, forestry, production and consumption, waste (**Figure 1**). Each subsystem is divided into distinct carbon compartments which

[1] The use of the mean annual increment and harvest according to NFI for single years or the use of interpolated values for single years would result in a higher uncertainty of the annual C-balance than the use of the calculated annual data.

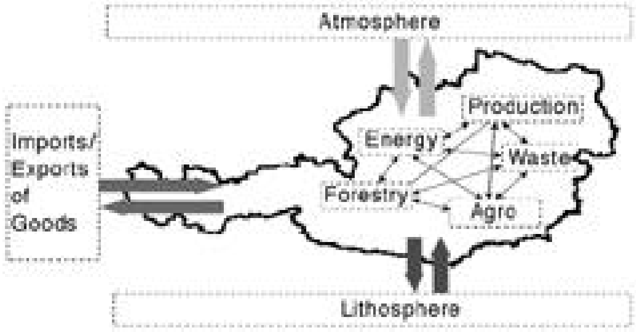

Figure 1. The ACBM system concept.

form the basis of carbon flux analysis and calculation. The outside system includes the carbon reservoirs beyond the system boundaries, i.e., atmosphere, the lithosphere, and goods and products that are imported or exported.

The "full" carbon balance approach has considerable advantages over the traditional emission inventory methodology (such as CORINAIR, EEA 1997 or IPCC, 1996). The "balancing" method allows to understand the complexity of the intra-system carbon flows and to minimise the uncertainties that are associated with some components of a national carbon system.

The project is a collaboration of three Austrian institutes:

– The Austrian Research Centers Seibersdorf (ARCS), Department of Environmental Planning (www.arcs.ac.at/S/SU) and Department of Environmental Research (www.arcs.ac.at/L/LA).
– The Joanneum Research Graz (JR), Institute of Energy Research (www.joanneum.ac.at/ief).
– The Institute for Industrial Ecology St.Poelten (IIE) (http://www.noe-lak.at/indoek/index.html).

The forest module in ACBM. Forest ecosystems as carbon sources or sinks are an important factor in the total national carbon exchange. Forest vegetation withdraws carbon dioxide (CO_2) from the atmosphere through the process of photosynthesis. Forest growth combined with the production of biomass accumulates carbon over a certain period of time, when carbon is stored in compartments of living vegetation, dead organic matter and the forest soil. For the ACBM Model an integrated dynamic model has been developed, focusing on the exploitable forest ecosystem in Austria defined as {FOREST} module and modelling the main processes that govern the role of vegetation, dead organic matter and soils, as well as the utilisation of biomass for energy use and timber production.

As part of the ACBM structure, the {FOREST} module is indirectly influenced by the driving parameters defined within all other ACBM modules. For example, the agricultural sector competes with the forest sector for lands. Other linkages are the demand of domestic industrial roundwood production from the {PROD} module and biomass (fuelwood and chips from harvest residues) used for energy by the {ENERGY} module.

Figure 2 shows the structure of the {FOREST} module in a simplified manner, boxes represent the carbon pools, arrows symbolise fluxes connecting pools. Within the system boundaries of the {FOREST} module six carbon pools are defined, five soil carbon pools containing dead organic matter and one vegetation pool. The vegetation pool is divided into the main part F_VEGETATION, representing the growing stock (tree biomass) and F_GROUND VEGETATION, covering the annual or perennial species growing on forest floor. Two different dead organic matter pools (F_WOODY LITTER and F_NON WOODY LITTER) and three mineral soil organic matter pools – F_ACTIVE MINERAL SOIL, F_STABILIZED MINERAL SOIL and F_INERT MINERAL SOIL represent the forest soil.

The model calculation, which also include changes in the age-class distribution due to varying harvest rates and natural disturbances, are done for the time period 1990–2010. The results of the {FOREST}

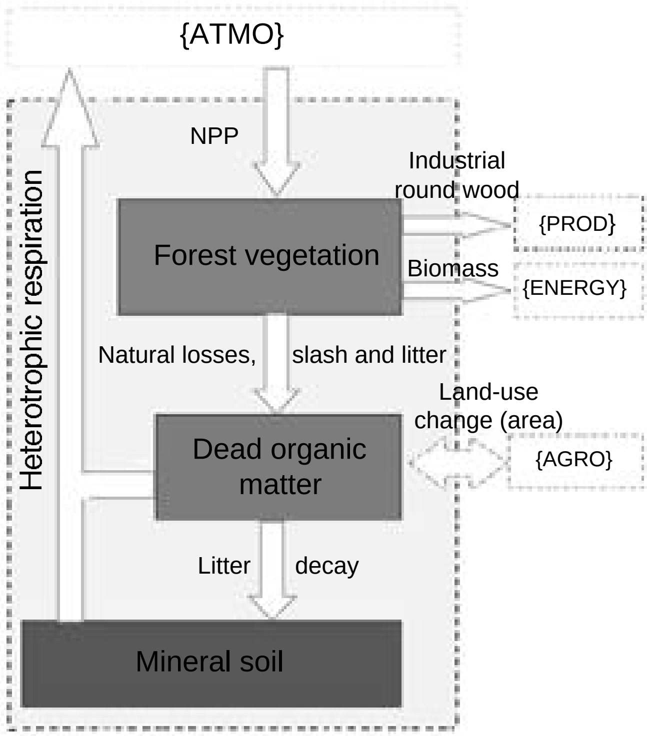

Figure 2. Simplified concept of the ACBM-FOREST module: carbon flows and pools, system boundary and connection to the other ACBM modules.

module mainly refer to the terms of Net Primary Production (NPP), Net Ecosystem Production (NEP) subtracting the amount of heterotrophic respiration and Net Biome Production (NBP) as the net annual carbon uptake or release of the entire forest ecosystem.

Results of the ACBM-FOREST module show that the forest ecosystem influences the Austrian national GHG balance significantly. The modelled total annual carbon sink (NBP) in the period of 1990–2010 is about between 5.9 and 10.7 Mt CO_2. The further results of the {FOREST} module and the ACBM Model will be available in the near future.

For information on § 2.2 please contact Rudolf.Orthofer@arcs.ac.at or hannes.schwaiger@joanneum.ac.at.

2.3. The Austrian carbon database (ACDb) project

The ultimate objective of the ACDb Project of the International Institute of Applied Systems Analysis (IIASA) is to support Austrian institutions dealing with matters related to the accounting of carbon or GHG emissions under the UNFCCC, including the Kyoto Protocol to this Convention. To these ends, the ACDb Project pursues three objectives. These include:

- support of the ACBM: in the form of a carbon consistent database,
- internationalisation: in the form of a framework that permits the placement of Austria's carbon account into an international science and policy context
- good practice: in the form of database-to-database consistency standards, identification of uncertainties, data completion for biological sources/sinks, etc.

The ACDb Project focuses on two questions:

1. How great are uncertainties in Austria's carbon data under full carbon accounting (FCA)?
2. What do these uncertainties mean in an international science and policy context?

Question 1 is in agreement with Objectives 1 and 3, while Question 2 coincides with Objective 2. The derivation of uncertainties and their treatment under FCA, as requested under Question 1, is new. Until now no other guide than classical statistics exists. In addition, addressing Question 2 requires a new methodology for handling uncertainty in consideration of verification.

The ACDb Project:

- Assembles officially reported or available data for many years. Presently, consistency procedures and uncertainty calculations (subjected to averaging) are done for 1990 or some centered time window around 1990.
- Takes a detailed (intra-database) as well as a synoptic (inter-database) view.
- Reports level (or total) uncertainties on aggregate (national) levels.
- Puts Austria's carbon account into an uncertainty-verification framework and thus into an international policy context (Jonas *et al.*, 1999a, b).

The forest module in ACDb. Uncertainties and other relevant information have been exchanged, in close collaboration, with the ACBM Forest Module (as well as other modules). Results will be reported after finalisation of the ACDb Project, after ensuring that they satisfy overall consistency.

For further information on the contents of § 2.3 please contact Matthias Jonas (jonas@iiasa.ac.at).

3. WORKING GROUP 2 RELATED ACTIVITIES (Analysis of forest management practices)

3.1. The forest model PICUS

The overall objective of activities at the Institute of Silviculture (Vienna Agricultural University) that are connected to WG II is to improve the forecasting capabilities regarding effects of changing environmental conditions and management operations on forest development. The modular structure of PICUS (**Figure 3**) allows for an enhancement of model components which are particularly important when addressing topics such as growth of mixed multi-aged species under changing climatic conditions (Lexer, Hönninger, 2000; Lexer *et al.*, 2000a, b). Currently a new approach to modelling tree growth within the classical patch model structure is being developed.

Using an improved forest model it is intended that management strategies will be developed in order to increase the sequestration and storage of carbon within the frame of a multiple-purpose forestry and to mitigate possible adverse impacts of a changing climate on forests.

Because Central European alpine forests serve a multitude of functions it might not be very realistic to assume that in the future these forests will be managed with the goal of maximizing carbon sequestration and storage. Thus, there is need to develop tools that allow for a sound consideration of trade-offs involved with alternative management options with regard to multiple objectives such as risk reduction, timber production, protective functions, conservation of biodiversity and sequestration of carbon. Such multiple-criteria decision making techniques and decision support tools are developed at the Institute of Silviculture and intended for managers in the field.

For further information on § 3.1 please contact Manfred Lexer (lexer@edv1.boku.ac.at).

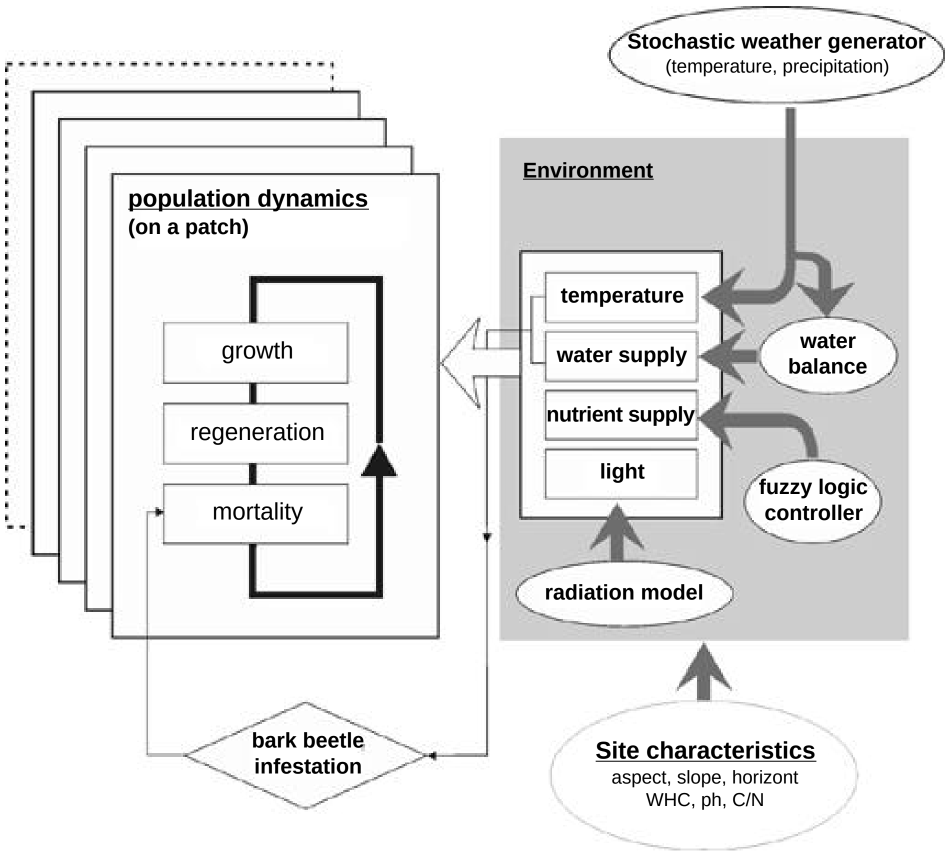

Figure 3. Core components of the forest model PICUS v1.2.

3.2. The carbon accounting model GORCAM

GORCAM (Graz/Oak Ridge Carbon Accounting Model) is a bookkeeping model that has been developed to calculate the net fluxes of carbon to and from the atmosphere associated with land management and biomass utilization strategies. The model can be applied at various levels (stand, landscape, regions, country), allows consideration of age-class dynamics and accounts for all effects along the full life cycle of wood products and biofuels. Sensitivity and uncertainty analyses are supported, and an economics module has recently been added. In particular, the model considers the following carbon-related effects:

– changes of carbon (C) stored in vegetation, plant litter and soil,
– reduction of C emissions because biofuels replace fossil fuels,
– C storage in wood products,
– reduction of C emissions because wood products replace energy-intensive materials like steel or concrete,
– recycling or burning of waste-wood,
– auxiliary fossil fuels used for production of biofuels and wood products.

Input parameters of the model describe the management regime (harvest cycle, growth rate, etc.), the land use before the project and the way in which the biomass is used for carbon mitigation. The model output is presented in diagrams with cumulative carbon sequestration over time.

The model is available free of charge provided a user agreement is signed. It has been widely distributed and used for carbon-balance studies (e.g. Schlamadinger, Marland, 1998; Marland, Schlamadinger, 1999). More information, including a model structure and typical model output can be found at: www.joanneum.ac.at/gorcam.htm. A list of all model equations can be found in Schlamadinger *et al.* (1997).

For further information on § 3.2 please contact bernhard.schlamadinger@ joanneum.ac.at.

4. PERSPECTIVES AND RESEARCH NEEDS

Research needs and possibilities for collaboration with other COST E21 countries are seen in the following areas:

– On-site measurements of carbon stocks (stock changes) for different forest management options, and model validation.
– Improvement of knowledge on soil carbon developments and their driving forces - in general and under different land use and land-use change scenarios.

- Collaboration on concrete LULUCF projects, such as in the framework of Article 6 of the Kyoto Protocol.
- Evaluation and improvement of process-based tree growth models as a prerequisite for the analysis of alternative management strategies.[2]
- Further developments of existing models and improvements of necessary data bases and calculation approaches.
- Collaborating on full carbon accounting projects.
- Cross checks between present methods to measure or calculate GHG balances and their uncertainties.
- Improvements of the present knowledge on other GHG emissions than CO_2.
- Improvements of methods to estimate the GHG emissions related to Kyoto lands or activities.

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