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Land-use Change and Forestry in Austria:
A Scientific Assessment of Austria's Carbon Balance in Light of Article 3 of the Kyoto Protocol

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Foreword

The Forest Resources Project at IIASA has the task, among others, to try and assess the carbon balance of boreal forests. In addition the project should carry out work which will support the implementation of the Kyoto Protocol. The project has recently carried out an assessment of the carbon balance in the Russian forest sector (published elsewhere) and found a number of issues that need to be further elaborated before the fullscale implementation of the Kyoto Protocol takes place. In order to assess whether our findings were specific for Russia or if they had a general feature, we found it important to also assess the carbon balance of other countries.

This work on Austria's carbon balance has verified that many of our concerns are of general character and not country specific.

Contents

Abstract

Article 3 of the Kyoto Protocol states that Parties included in Annex I shall use net changes in greenhouse gas emissions from sources and removals by sinks resulting from direct human-induced land-use change and forestry (LUCF) activities since 1990 to meet their emission reduction commitments. However, even with clear guidelines on how to calculate LUCF emissions and removals, considerable problems remain.

Our paper addresses a number of relevant issues by summarizing the knowledge gained from assessing and quantifying sources and sinks of carbon compounds relevant to Austria on the basis of an integrated operational model framework, the *Austrian Carbon Balance Model* (ACBM). The ACBM covers Austria's biosphere and technosphere and at present permits project researchers to run a Reference Scenario for 1990–2050.

We attempt to generalize our experience and also to compare our model results regarding Austria's net atmospheric carbon contribution on the basis of the uncertainties underlying these results. This permits us (1) to identify several high-priority research issues that will enable Austria to cope adequately with its commitments under the Kyoto Protocol; and (2) to draw general conclusions that may provide support to the Conference of the Parties as it decides upon modalities, rules and guidelines in accounting for LUCF emissions and removals.

Key Words: Climate Convention, Kyoto Protocol, Article 3 , net emissions, land-use change, forestry

Acknowledgments

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1.   Introduction

Article 3 (Nos. 3 and 4) of the *Kyoto Protocol to the United Nations Framework Convention on Climate Change* (UNFCCC, 1997, 1998) states that:

> *3.   The net changes in greenhouse gas emissions from sources and removals by sinks from direct human-induced land use change and forestry activities, limited to afforestation, reforestation, and deforestation since 1990, measured as verifiable changes in stocks . . . shall be used to meet the commitments under this Article of each Party included in Annex I. . . .*

and

> *4. . . . each Party included in Annex I shall provide . . . data to establish its level of carbon stocks in 1990 and to enable an estimate to be made of its changes in carbon stocks in subsequent years. . . .*

However, fulfilling these commitments is not a straightforward task. Article 3 (No. 3) reveals serious scientific shortcomings, e.g., a lack of guidance on to how to deal with disturbances, including harvest and storage of carbon in wood, or whether to consider land-use change and forestry (LUCF) activities prior to 1990. Also, both Article 3 (No.3) and Article 3 (No. 4) implicitly require that countries precisely calculate net changes in greenhouse gas emissions and removals based on changes in carbon stocks, despite the inherent uncertainties in measurements, data, etc. — an unrealistic expectation in the case of Austria (and possibly other countries), as our paper shows. Therefore, even in the presence of clear guidelines on how to calculate emissions and

removals resulting from human-induced LUCF activities, considerable problems remain (see also Bolin, 1998).

Our paper addresses some of these issues and other relevant problems by summarizing the insight gained from assessing and quantifying sources and sinks of carbon compounds relevant to Austria on the basis of an integrated operational model framework, the *Austrian Carbon Balance Model* (ACBM). The ACBM, which is being developed by several Austrian scientific institutions, including and under the coordination of the Austrian Research Centers Seibersdorf, covers Austria's biosphere and technosphere and currently enables our project researchers to run a Reference Scenario for 1990–2050.

Analyzing Austria's net atmospheric carbon contribution and its underlying uncertainties permits us (1) to identify a number of high-priority research issues that will enable Austria to cope adequately with its commitments under Article 3 of the Kyoto Protocol; and (2) to draw general conclusions that may provide support to the Conference of the Parties as it engages in future deliberations to decide upon modalities, rules and guidelines in accounting for LUCF emissions and removals — also specified in Article 3 (No. 4) of the Kyoto Protocol.

While the experience gained from building and running a model has always proven very helpful in identifying and quantifying the problems addressed in Section 3 below, the modeling approach is by no means mandatory. However, before focusing on five key issues, all of which relate to the biosphere, we provide a brief description of the ACBM.

2.   The Austrian Carbon Balance Model

Since 1995 the Austrian Research Centers Seibersdorf have coordinated work related to a project titled *Systems Analytical Assessment of Austria's Carbon Balance*. The project aims at assessing and quantifying sources and sinks of carbon compounds relevant to Austria on the basis of a synoptic systems-analytical approach, i.e., a dynamic computer simulation model (Jonas, 1997; Mayr et al., 1997; Schidler, 1998). It incorporates carbon-relevant human activities, pools, fluxes and feedbacks that have been identified as being important in determining Austria's carbon balance until 2100 (see Table 1).

Based on these preliminary systems insights, an integrated operational model framework, the Austrian Carbon Balance Model (ACBM), has been designed. This model includes the following components (see Figure 1): Austria's biosphere, encompassing modules for forestry and agriculture, and Austria's technosphere, encompassing a set of submodules ranging from energy to wood and food & feed industries to biomass-relevant products, including biogenic waste. This paper discusses the ACBM at the module level only where appropriate and to the extent required.

The main task of the project is to combine, interpret, and communicate knowledge from diverse scientific disciplines, via an interdisciplinary and participatory process, and thereby to improve understanding of a complex phenomenon: Austria's carbon budget and its dynamical behavior. The project does not seek to generate deeper intra-disciplinary insights, but instead strives for added value compared to insights derived from single-disciplinary research.[1]

The ACBM has demonstrated the capability of capturing the essential carbon-relevant human activities, pools, fluxes and feedbacks identified in Table 1, and of eventually becoming a fully integrated model. The first modeling phase (which lasted until the end of 1997) provided an operational framework that forms a satisfactory basis for expanding the ACBM during a second phase, which will be conducted in collaboration with other scientists and in a fully interdisciplinary manner.

As noted above, we have used the ACBM to create a Reference Scenario for Austria for 1990–2050.[2] We defined this scenario to include: (1) a reference scenario for the energy system, based on Scenario A1 (selected region: Western Europe) of the global study conducted by the International Institute for Applied Systems Analysis (IIASA) and the World Energy Council (WEC); and (2) a scenario that keeps current (1990) land-use/cover conditions constant into the future for the remainder of the ACBM's coverage period. Again, this paper will discuss results of the (combined) scenario only if appropriate and to the extent required.

3.   Austrian Experience Relevant to Article 3 of the Kyoto Protocol

In this section we will examine five key issues relevant to Article 3 (Nos. 3 and 4) of the Kyoto Protocol, all of them related to the biosphere. Our findings indicate that Austria's emissions from the use of fossil fuels can be determined adequately, while it is not yet possible to assess biosphere uncertainties and nonlinearities equally well.

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[1] Here we make use of one of the definitions of *Integrated Assessment* (IA) that are widely discussed across scientific communities at present [Granger Morgan and Dowlatabadi (1996); Rotmans et al. (1996a, b); J. Rotmans (1997; personal communication); van Asselt et al. (1997); IIASA (1997)].

[2] The forestry and agriculture module takes account of LUCF activities prior to 1990, as described in Table 3 below.

3.1   A Consistent LUC Database

Although it is nowhere explicitly mentioned, a prerequisite for any accurate inventory of natural greenhouse gas emissions and removals is the use of a consistent land-use/cover (LUC) database that provides data coverage for a country's total territory.[3] By "consistent" we mean a data resource that (1) harmonizes LUC statistics with legal land registry data, and (2) assembles the most reliable LUC data files from different data sources, thereby accurately reflecting conditions in the entire country. In addition, a consistent LUC database reduces statistical errors. High statistical accuracy is essential not only for preparing national greenhouse gas inventories, e.g., by making use of the revised 1996 IPCC Guidelines (IPCC, 1997a, b, c), but also for building a model such as the ACBM.

However, consistent LUC databases are usually not readily available or, if available, may not reach back sufficiently long into the past. The following examples illustrate typical data inconsistencies and/or inhomogeneities we faced in analyzing the case of Austria:

1) While several national LUC databases exist, their data reliability has proven limited. This has occurred because national institutions that maintain LUC databases usually gather information directly on only limited subsets of a country's land use and land cover, and derive the remainder of their data from statistical balancing.

2) Surveys aimed at deriving LUC datasets may not take place at regular intervals (in fact, they may sometimes be conducted only upon request), and may not always be based upon spatially fixed survey grids.

3) A change in the minimum survey area unit, as for instance, happened in Austria between 1982 and 1983, can significantly affect data accuracy and any subsequent assessments. The minimum area unit considered in LUC surveys until 1982 was 0.5 hectares; thereafter, the unit used was 1 hectare, with the consequence that small-scale areas in particular experienced disproportionate survey changes (e.g., small farms, which are typical for Alpine regions).

4) The researchers encountered several land-use/cover misclassifications, for instance, when financial incentives in the agricultural sector favored a certain type of land use or land cover. In this case, LUC data are usually distorted in favor of the financially more attractive option.

There exist numerous such data inconsistencies and inhomogeneities, which generally become apparent if the data are tested against a country's total area, and, whenever possible, against other, independent data sets, such as those derived from remote sensing. Our experience leads us to conclude that extracting the most reliable LUC data

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[3] The terms *land use* and *land cover* employed here and in the following are in line with the definitions used by the IGBP (1993, 1995).

subsets and piecing them together into a nationally consistent LUC database does help both to reduce data uncertainties considerably and to increase confidence in data reliability.

The ACBM project sought to establish a consistent LUC database for Austria, covering the years 1960–1990 (see Figure 2). All details concerning data sources, data processing, etc., are described in Schidler (1998); for a summary at a somewhat less detailed level see also Jonas (1997). This consistent LUC database served as the basis for Austria's last inventory of its natural greenhouse gas emissions and removals (FMEYF, 1997), and was also used in the ACBM.

3.2   Assessing the Combined Effect of Past LUC Changes

A consistent LUC database is necessary, but by no means sufficient, to estimate carbon fluxes in a given inventory year that result from changes in land use and land cover. This task requires taking into account events over long periods of time. In particular, if different changes in land use and/or land cover overlay each other, it is almost impossible to judge the resulting effect without making use of direct measurements of changes in carbon stocks.

The practical first-order approach currently being recommended by the IPCC (1997a, b, c) is to make simple assumptions about the effects of land-use changes on carbon stocks (for example, in existing biomass and soils) and about the subsequent biological responses to the land-use change, and to use these assumptions to calculate carbon stock changes and hence the CO_2 flux.[4] However, complying with this "simple" procedure requires awareness of difficulties, in particular when assessing the combined effect of changes in both land cover and land use. The following example illustrates the importance of this point.

Land-cover Change

Figure 2 shows net changes in Austria's land use and land cover. However, to calculate changes in soil carbon properly, researchers must know about individual land-cover changes.

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[4] In the original text (IPCC, 1997c: p. 5.3) only the term *land-use change* is used. However, the use of this term throughout the revised 1996 IPCC Guidelines (IPCC, 1997a, b, c) refers to changes in both land use and land cover, as defined by the IGBP (1993, 1995) (see also Footnote 3).

For instance, according to Figure 2, Austria's total forest land[5] increased between 1960 and 1990, mainly at the expense of Austria's arable land and grassland.[6] Losses of grassland, in turn, occurred not only in favor of Austria's forest land, but also, to some (minor) extent, in favor of Austria's arable land. Yet, in spite of these gains, the arable land experienced greater losses in favor of Austria's forest land (W. Bittermann, 1998; personal communication). Therefore, and because on a per-hectare basis carbon stocks in grassland soils exceed those in arable land soils, soil carbon in Austria's arable land, on average, should have increased.

Land-use Change

The past increase in agricultural yield per hectare of cereals and crops constitutes an important change in land use.[7] For instance, between 1960 and 1990 the range of cereal yield for wheat, rye, barley, oats and corn increased from [2.0, 3.8] to [3.9, 8.2] tons per ha^{-1}, where oats and corn provide the lower and upper values, respectively. From our data compilations that also consider the shifting of species, we can conclude that this increase in yield, on average, is equivalent to an increase in total plant carbon content. Higher total plant carbon content, in turn, tends to induce higher carbon content of harvest and root residues, which promote carbon sequestration.[8] Therefore, in the case of land-use changes our conclusion would also be that, on average, soil carbon in Austria's arable land should have increased.

However, large-scale measurements of carbon in humus (0–20 cm) on Austria's arable land between 1965 and 1991 that have recently been made available (Dersch and Böhm, 1997a, b) seem to indicate a mean loss rate of 0.24 tC ha^{-1} yr^{-1}.[9] Therefore, other changes must have occurred, such as alterations in agricultural management practices

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[5] To reflect Austrian conditions, the term *total forest* used here is equivalent to *forest* as defined by the UN (1992) minus land used for short-rotation plantations.

[6] In Austria, forest land increased from about 3,541*10^3 ha in 1960 to about 3,880*10^3 ha in 1990; grassland decreased from about 1,408 * 10^3 ha in 1960 to about 1,078*10^3 ha in 1990; and arable land decreased from about 1,524 * 10^3 ha in 1960 to about 1,372*10^3 ha in 1990.

[7] In the model, yields of cereals and crops are simplified in that they represent area-averaged means over a range of cereal and crop species in terms of their yields. *Cereals* are defined to include wheat, rye, barley, oats and corn; *crops* are defined to include potatoes, legumes, clover-hay, maize for silage purposes, sugar beets, fodder beets, sunflowers, rape and oil-pumpkins. According to the data of the Austrian Central Statistical Office, this (incomplete) breakdown of cereals and crops covers about 88% or even more of (1) the harvested amounts of all cereals and crops (in terms of mass) during 1950–1990; and (2) the land cover of all cereals and crops (in terms of area) during the same period (Schidler, 1998). Based upon the above definition of *cereals* and *crops*, the figures for arable land during 1950–1990 were increased; that is, the amounts for land of each cereal and crop species were raised proportionally to match the nationally consistent and smoothed arable land data shown in Figure 2.

[8] Given the lack of data, we have so far assumed in our LUC database that the ratio of carbon content of plant and root residues to total plant carbon content stays constant over time. However, we note that this assumption is critical and awaits improvement.

[9] As emphasized by the authors, disregarding a thinning effect as a result of deeper plowing practices.

(for example, on-site burning[10] or removal of straw), and/or increases in tillage and harvest intensity and in tillage depth, possibly in combination with an increase in compaction, particularly at greater depths (Dersch, 1998; personal communication). The combined effect of these different activities is difficult to quantify over time and contradicts our previous assumptions of increasing soil carbon stocks. Interestingly enough, these measured carbon losses from Austria's arable land soils are lower by about a factor of three compared with estimates according to the revised 1996 IPCC Guidelines.[11]

Therefore, given the long time periods and large areas usually involved, one can expect considerable uncertainties related to assessing the combined effect of past LUC changes on a country's level of carbon stocks in 1990. One cannot simply make comparisons with other carbon fluxes contributing to a country's greenhouse gas balance to determine whether or not significant annual changes in carbon stocks (losses of humus carbon) will occur currently and in the future. Instead, the changes should be examined by considering the level of carbon stock (i.e., the humus carbon pool) in question.

3.3 Classifying Emissions

For political reasons, it is undoubtedly important to include as many radiatively active and relevant trace gases in a country's greenhouse gas inventory as possible. However, attempts to classify these emissions by sources and removals by sinks focus on terms such as *man-made* and *natural*, which seems to present more problems than solutions, especially in regard to the boundary between the two types of emissions (EEA, 1996; IPCC, 1997c; Winiwarter et al., 1998). Closely related to this classification issue is a similar one that we faced in the ACBM: namely, how to define the terms *biosphere* and *technosphere*.

It is critical to note that while these classification attempts may be of academic interest, they cannot be firmly incorporated into source/sink calculations. This is shown by the continuity equation in physics, which expresses the conservation of mass, energy, etc., and can be easily demonstrated with the help of Figure 3 and Table 2. Figure 3 shows the agricultural module at a submodule level. As can be seen, we introduced a domestic "harvest meter," which tracks harvested carbon and its distribution. In addition, it provides an auxiliary means to define the boundary between *biosphere* (right; excluding *Feed from Technosphere*) on the one hand and *technosphere* (left; including *Feed from*

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[10] Austria has forbidden the on-site burning of agricultural residues since 1991 [Federal Law Gazette 1993/405; see also Steinlechner et al. (1994)].

[11] According to first model results (Jonas, 1997), which agree with the field data reported by Dersch and Böhm (1997), the decomposable carbon pool of Austria's arable land decreased from about 49.7 tC ha^{-1} in 1950 to 40.8 tC ha^{-1} in 1990, that is, by about 9% over 20 years. According to the revised 1996 IPCC Guidelines (1997c; Table 5-12) the mean change in soil carbon over an inventory period of 20 years is about $(1 - 0.7 *1.0 * 1.0)$ or 30%, assuming the following default values: (1) a base factor of 0.7; (2) a tillage factor of 1.0; and (3) an input factor of 1.0.

Technosphere) on the other hand, and thus to separate the two. This unconventional definition at least helps to avoid lengthy explanations that may be required otherwise.[12]

Table 2 presents a conservative estimate of the 1990 carbon sink strength of Austria's biosphere. It also demonstrates that it does not matter where we set the boundary between biosphere and technosphere as long as the estimate includes no additional sources or sinks. In our model, *biosphere* is defined to encompass (1) agriculture, including husbandry (cattle and swine); and (2) forestry, where the forest sink strength is a total sink strength and is not yet limited to afforestation, reforestation, and deforestation (definition I in Table 2). In the case of the agricultural system, carbon sources are ultimately related to soils.[13] However, this unconventional definition of *biosphere* results in a biospheric sink strength identical to the one defined: to consist only of the living biomass-litter-soil system (definition II in Table 2). Therefore, when attempting to classify emissions by sources and removals by sinks, we suggest for scientific reasons that the Protocol avoid imprecisely defined terms such as those mentioned above.

3.4   Definition of a Baseline Scenario

In our attempt to couple biosphere and technosphere (used here as defined in the ACBM; see Subsection 3.3 above), an important concern was which scenario to use as a Reference Scenario. In addition, we had to take account of the model's current capabilities. With this in mind, we defined the *Reference Scenario* in our study to be a generic term for (1) a reference scenario for the energy system, based on Scenario A1 (selected region: Western Europe) of the global IIASA-World Energy Council study (IIASA-WEC, 1995; Nakicenovic et al., 1997); and (2) a scenario that keeps current (1990) land-use/cover conditions constant into the future for the remainder of the ACBM. Table 3 presents detailed information describing the Reference Scenario.

At a less detailed level, the following two points may be worth noting in this context:

- Our reason for favoring this definition is based on the knowledge available regarding Austria's technosphere, which is far better captured in the form of models and investigated in terms of how it may look in the future than Austria's biosphere. Therefore, we needed a standard in studying the projected state of Austria's

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[12] We note that *biosphere* is a well-defined term (see, for instance, *The New Encyclopædia Britannic*a), while this is not the case with *anthroposphere* and *technosphere*.

[13] Husbandry, if properly balanced in terms of feed uptake, respiration, etc., cannot be regarded as a source or sink on a multi-year scale unless a country's cattle stock increases or decreases markedly during this time.

biosphere, and as a result we kept current LUC conditions constant in our attempt to run a Reference Scenario of the future.

- The model chosen to represent the energy system of Austria's technosphere is the *energy-CO$_2$ modeling framework for Austria* (identified in Figure 1 as the IIASA/TU Graz model), developed through a collaborative effort by IIASA and the Graz University of Technology (Nakicenovic et al., 1997). This model incorporates an energy scenario formulation framework and uses a reference scenario that is consistent with global energy perspectives of the IIASA-WEC study (IIASA-WEC, 1995). As Nakicenovic et al. (1997) point out, their model represents the first time that components of IIASA's global-scale framework have been applied to develop scenarios for an individual country.

  The IIASA/TU Graz model consists of three parts: (1) a parametric energy-economy model scenario generator; (2) the energy systems model MESSAGE; and (3) a CO$_2$ mitigation technology data bank. In the current version of the ACBM, the IIASA/TU Graz model is run in a standalone mode and its results (such as primary energy demand and carbon emissions due to fuel combustion) are fed back to the ACBM, where they are implemented (in the form of polynomial parameterizations) in the technosphere module. We note that this soft-link approach represents only an intermediate step on the way toward a more rigorous attempt to model an energy-industry-product system, but it seemed the most appropriate option given the great imbalance of carbon flows between technosphere and biosphere.[14]

We expect that scientific discussions on defining an appropriate baseline scenario will continue, and that the IPCC will stimulate them to focus at an international level on the topic of comparing and reconciling global *top-down* with regional *bottom-up* greenhouse gas emission inventories (see, for example, Olivier et al., 1996).

3.5   The Concept of Net Emissions versus Uncertainties

Table 4 summarizes some of the most important knowledge we gained from constructing a Reference Scenario as outlined in the previous subsection. The table relates estimates of the maximum change in Austria's net carbon flow into the atmosphere between 1990 and 2050 (which, as Figures 4a and 4b show, is dominated by Austria's energy system as a strong carbon source and its exploitable forest system as a strong carbon sink) to various uncertainties in the Austrian data. The disparate outcomes result from using different or uncertain Austrian data reflecting conditions as of 1990 (in most cases in Austria's exploitable forest), such as:

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[14] In 1990 the overall flow of carbon from biosphere to technosphere exceeds the overall flow of carbon from technosphere to biosphere by a factor of about 5 to 6 (Jonas, 1997).

- the total uncertainty in source-sink calculations based on the IPCC Guidelines from Worksheet 5-1 (*Land Use Change and Forestry: Changes in Forest and Other Woody Biomass Stocks*) (IPCC, 1995a, b, c), where we apply moderate uncertainties regarding (1) the area of Austria's exploitable forest (±5%); (2) its annual growth rate (±5%); and (3) the commercial harvest as reported by the Austrian Central Statistical Office (±3%);

- the uncertainty in ΔGS, the annual growing stock change;

- the uncertainty in statistics regarding domestic fellings and yield; and

- the statistical uncertainty related to Austria's use of fuel wood.

All values are given as absolute numbers. In addition, we took into account:

- a statistical uncertainty related to the total flux in Austria's biogenic decay ; and

- an uncertainty related to soil carbon losses from Austria's arable land.

The latter is smaller than the other uncertainties listed in Table 4, but definitely not less important when we recognize that carbon content in Austria's arable land decreased by about 13% on average between 1965 and 1991, according to Dersch and Böhm (1997a, b).

It is important to realize that these uncertainties have been identified individually, but that many of them act together in some combination that we have not yet explored. In addition, we must recognize that still other important uncertainties remain, such as those related to determining the amount of phytomass, the dynamics of soil organic carbon, or the impact of natural disturbances on increment and growing stock. However, given our insufficient knowledge, we cannot yet quantify these with confidence, and, therefore, we do not take them into account here.

In any case, we can legitimately conclude that at present our incomplete knowledge about biospheric processes and data in particular makes it impossible to carry out rigorous calculations of net emissions. In general, this conclusion should also hold if only human-induced land-use change and forestry activities are considered, as Article 3 (No. 3) of the Kyoto Protocol requires. For this scientific reason we argue that an approach should be preferred that involves separately quantifying individual and total carbon flows to and from the atmosphere, taking into account the related uncertainties, to one depending on the concept of net carbon flows.

4. Conclusions

The foregoing discussion drew attention to five key issues that have bearing on Article 3 (Nos. 3 and 4) of the Kyoto Protocol. On the basis of this discussion, it seems that political intentions, rather than scientific principles, have determined some of the language contained in the Kyoto Protocol. We outlined a number of scientific problems that the modeling team encountered in developing a scenario for Austria, and that could possibly also hinder other countries in complying adequately with their commitments under Article 3 of the Protocol.

By contrast, some of the problems also fall partly or fully beyond the scientific competence of a single country and require international scientific agreement. The IPCC Guidelines (1995a, b, c; 1997a, b, c), developed to establish a common base for determining changes in sources and sinks, may serve this purpose. However, we must keep in mind that these guidelines were not designed to serve as a legal basis for compliance (Bolin, 1998). We therefore foresee the need to agree on a scientifically adequate methodology that permits compliance with the commitments under Article 3 of the Kyoto Protocol.

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15

Figures

Fig. 1. Aggregated ACBM structure and carbon flow overview chart of Austria. Biomass-relevant industries (wood and food & feed sectors) are treated separately within the technosphere module, thus making it possible to establish appropriate links to the forestry and agriculture module.
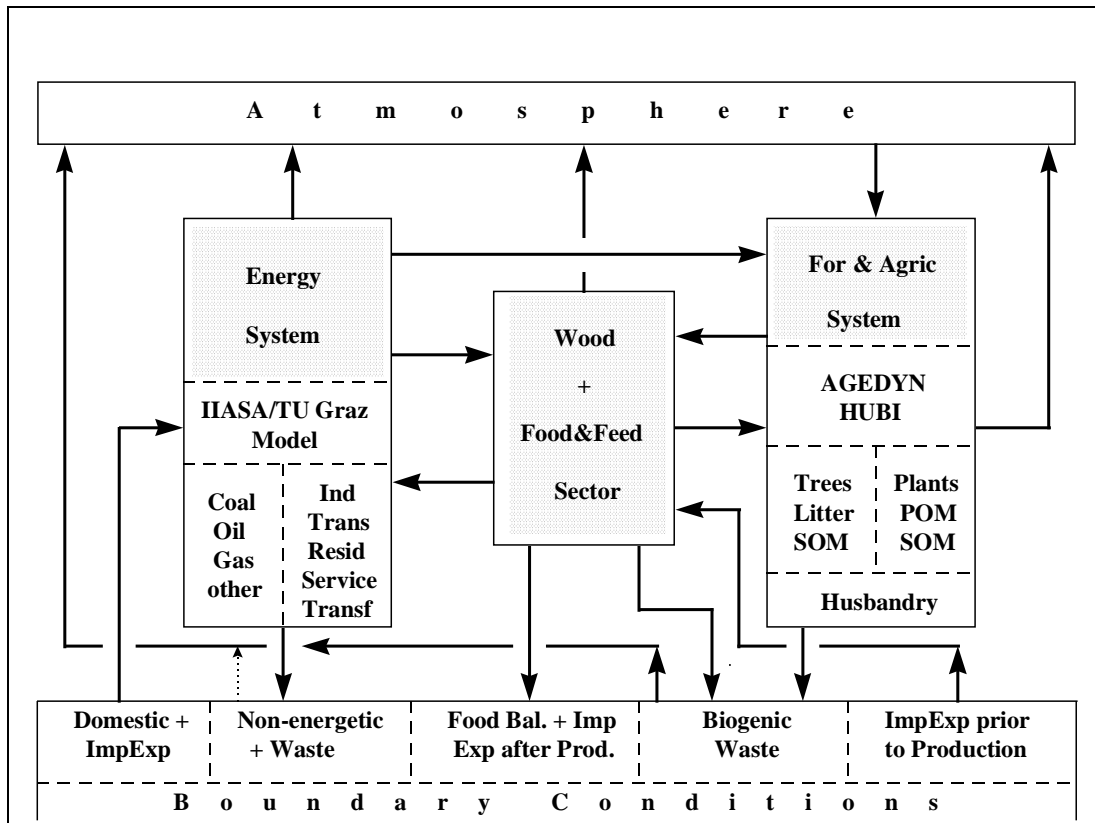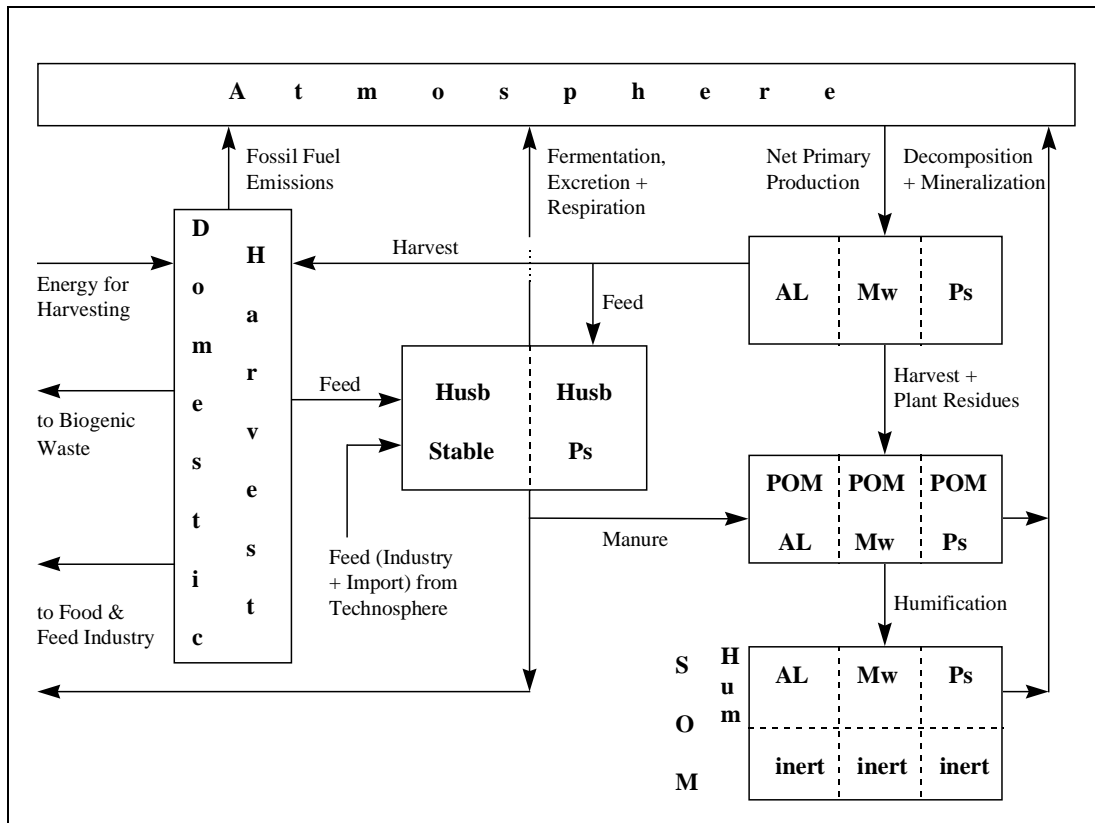

Source: Jonas (1997)

Fig. 2. Consistent LUC database for Austria (in 10^6 ha): 1960–1990.
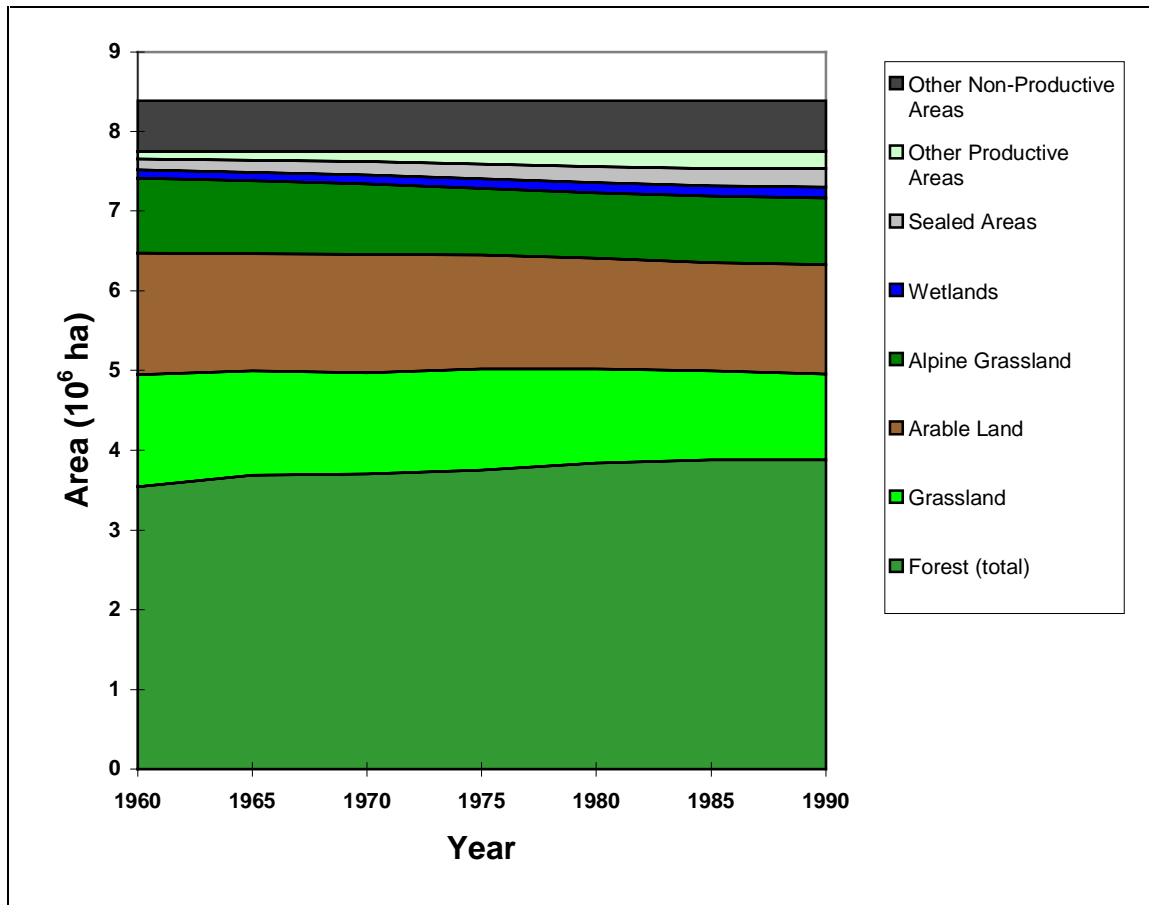
Source: Schidler (1998)

Fig. 3. Detailed structure of carbon pools in the agriculture module.

Explanatory key:

AL   = Arable Land   Hum = Humus

Mw = Meadows   POM = Primary Organic Matter

Ps   = Pastures   SOM = Soil Organic Matter

Husb = Husbandry

Source: Jonas (1997)

18

Fig. 4a. Austria's atmospheric carbon balance 1990–2050 according to the Reference Scenario (see Table 3): Inflows versus total outflow.
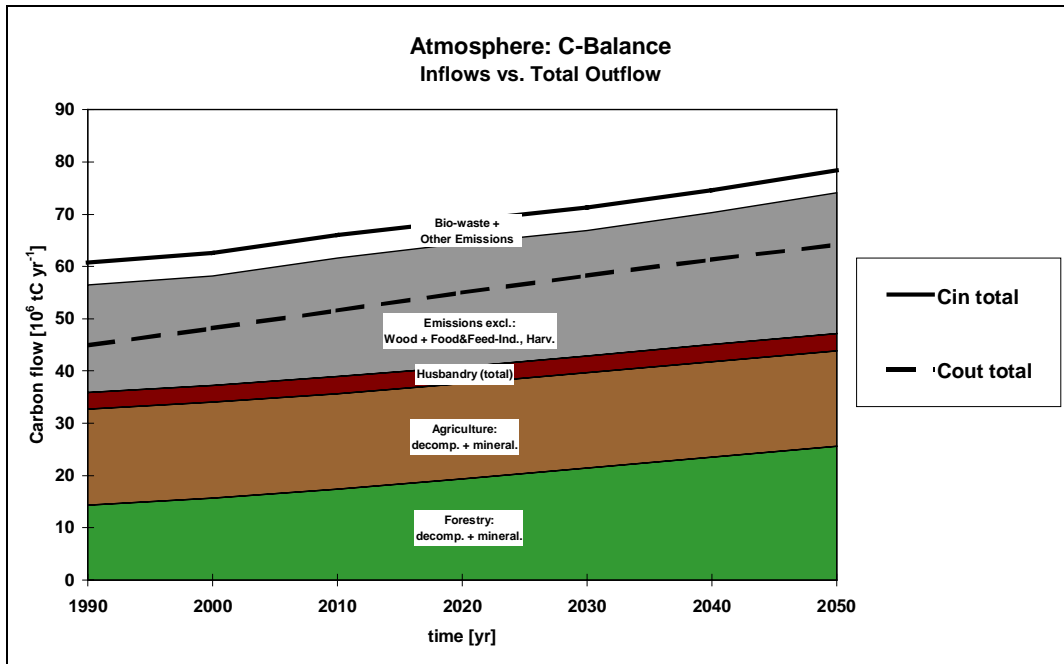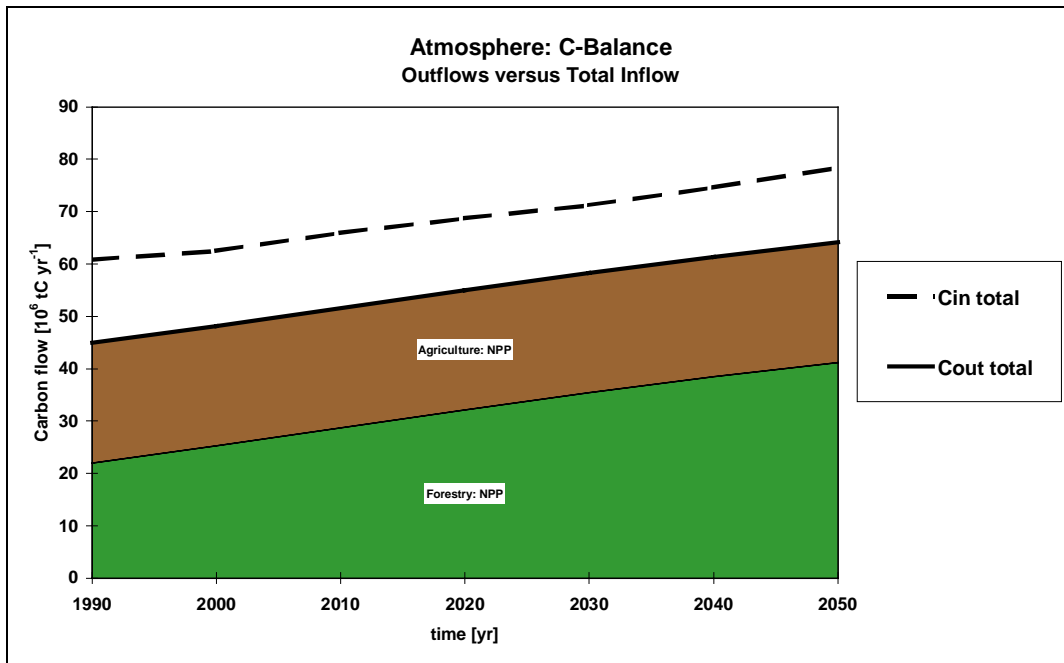

Fig. 4b. Austria's atmospheric carbon balance 1990–2050 according to the Reference Scenario (see Table 3): Outflows versus total inflow.

Source for Figures 4a & 4b: Jonas (1997)

Tables

Table 1. Carbon-relevant human activities, pools, fluxes and feedbacks of importance to Austria until 2100.

To be considered . . .	because of . . .	Relevant or characteristic (average) time scale involved
Anthropog. activities related to energy use in form of fossil fuels, C storage and substitution	Fossil fuel use Biomass use Use of other renewables	Anthropog. controllable; typical time scale for accounting: ≈ 1 yr
Terrestrial biosphere	C-relevant pools and/or fluxes: Forest and forest soils Grassland soils Arable land soils	≥ 1 yr . . . ≥ 100 yrs typical range of litter and soil pool turnover times
Anthropog. activities or processes related to land-use/cover	Forest management Land conversion Soil degradation (humus C)	Anthropog. controllable; typical time scale for accounting: ≈ 1 yr . . . ≥ 5 yrs
Global feedbacks	CO_2 fertilization Temperature increase Nitrogen fertilization	Still subject to scientific clarification; small-scale experimental studies suggest time scales of ≥ 1 yr . . . ≥ 10 yrs and beyond for noticeable feedbacks

Sources: Atjay et al. (1979), Bolin et al. (1979), Hampicke (1980), Bolin (1986), Budyko and Izrael (1991), Jenkinson et al. (1991), Raich and Schlesinger (1992), IPCC (1995)

Table 2. Carbon balance of Austria's biosphere (forestry and agriculture) for 1990. The sink strength of Austria's exploitable forest represents a conservative estimate and a total sink strength, which is not yet limited to afforestation, reforestation, and deforestation.[15]

1990 Carbon Balance of Austria's Biosphere[a] (Forestry[b,c] and Agriculture)		
Flows to and from Austria's Biosphere System	**Value** 10^6 tC yr^{-1}	
Into the Biosphere System		
Photosynthesis	44.9	
Fossil fuel input for harvesting	0.2	
Feed to husbandry	0.8	D
Total	**45.9**	E
Out of the Biosphere System		F.
Decomposition, mineralization, husbandry, emissions due to harvesting	36.0	I
Harvest (uncorrected in case of forest harvest)	4.6	
Biogenic waste (agriculture)	0.5	
Total	**41.1**	
Sink Strength		D
Exploitable forest sink strength	5.0	E
Sink strength of agricultural soils (arable land, pastures)	− 0.2	F.
Total	**4.8**	II

[a] Here *biosphere* is defined to include forestry and agriculture. This definition is an unconventional one and deviates from widely accepted standard definitions.

[b] Note that the term *forestry* refers to Austria's exploitable forest.

[c] The conversion factor underlying this table to calculate in particular wood carbon contents (in tC) and total tree biomass (in tC) from usable stem wood (in m^3 o.b.) is 0.28. The revised conversion factor is 0.36.

Source: Jonas (1997)

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[15] See Jonas (1997) for the complete set of simplifications, model restrictions and modeling assumptions.

Table 3. Description of the Reference Scenario for Austria, as implemented in the present version of the ACBM. The term *Reference Scenario* is a generic term and includes: (1) a reference scenario for the energy system, as already defined by Nakicenovic et al. (1997); and (2) a scenario that keeps current (1990) land-use/cover conditions constant into the future for the remainder of the ACBM.

Technosphere			Biosphere	
The energy system follows the reference scenario defined by Nakicenovic et al. (1997) for application of their *Energy-CO₂ Modeling Framework for Austria* (IIASA/TU Graz model). Austria's wood and food & feed sectors are not yet dynamic and reflect current land-use/cover conditions of the biosphere (see right).			Agriculture and forestry follow current (1990) land-use/cover conditions into the future.	
Energy System	**Wood Industry**[a] **Food & feed Industry**	**Product (long)**[a] **Product (short)**	**Agriculture**	**Forestry**
– based on Scenario A1 (selected region: Western Europe) of the global IIASA-WEC study (IIASA-WEC, 1995) for 1990–2050; scenario represents a future designed around ambitiously high rates of economic growth and technological progress – average per capita GDP growth rate of 1.62% yr⁻¹ between 1990 and 2050 (Western Europe: 1.73% yr⁻¹) – increase in Austria's population by 0.11% yr⁻¹, i.e., from 7.71 * 10⁶ hd in 1990 to 8.22 * 10⁶ hd in 2050 (Western Europe: 0.22% yr⁻¹) – world market prices of globally traded energy carriers derived from the IIASA-WEC study; domestic fossil energy supply continues to decrease	– final energy demand follows overall trends in agreement with the IIASA/TU Graz reference scenario (see left) for the industrial sector [fuels (total): –0.49% yr⁻¹; electricity: 0.18% yr⁻¹] – constant *domestic fellings* input [corrected to satisfy mean yield statistics of the Austrian Central Statistical Office for 1989–1991; cf. Jonas (1997), Table 2.2-6] – *biomass for energy* variable [corrected for 1990 to overcome both: (1) considerable inconsistencies in the statistics of the Austrian Institute of Economic Research and the Austrian Central Statistical Office and (2) a not (yet) perfect tuning of the IIASA/TU Graz model in the context of this	– constant domestic production of long-lived wood products [tuned to satisfy 1989–1991 average conditions; cf. Jonas (1997), Table 2.4-2] – production and decay of long-lived products in the past is assumed to be the same and comparable to their today's production and decay, that is, a time-dependent decay effect is not considered here [cf. Jonas (1997), Appendix II] – *biogenic waste* of short-lived wood and food & feed products is assumed to happen quasi instantaneously, that is, a time-dependent decay effect is not considered here – contrary to the IIASA/TU Graz reference scenario (see left), an	– land-use/cover pattern as of 1990 [cf. Jonas (1997), Appendices I and III] assumed to be the same for the future – calculating changes in the amount of humus carbon requires to take past land-use/cover into account: *arable land:* Austria's arable land as of 1990 combined with surrogate land-use conditions as of 1950 and tuned to comply with total loss of humus carbon acc. to Dersch and Böhm (1997a, b) and with surrogate changes in land-use conditions until 1990 *meadows:* humus carbon pool tuned to stay constant under 1990 harvest conditions because of not readily available long-term measurement series	– land-use/cover pattern as of 1990 [cf. Jonas (1997), Appendix I] assumed to be the same for the future – focus on Austria's exploitable forest, excluding pre-commercial thinning – calculating changes in living biomass, litter and soil carbon requires to take past forest growth into account: AGEDYN, the forest growth model implemented, is tuned to comply with monitored forest growth between the two forest inventories 1981/85 and 1986/90; earlier start of forest growth model desirable, but not possible of not readily available

– decrease in final energy intensity by 1.39% yr^{-1} between 1990 and 2050, relative to 1990 (Western Europe: 1.43% yr^{-1}) – efficiency improvements mainly in the residential/commercial and industrial sector and in the energy conversion sector; new technologies and their learning curves based on Scenario A1 of the IIASA-WEC study – 300 PJ potentially available from biomass until 2020; another 100 PJ until 2050 – increase in hydropower from 110 PJ in 1990 to 195 PJ in 2050, assuming utilization of all technically and economically feasible hydropower potentials until 2050 – increase in other renewable energy options (wind, photovoltaics, solar), but total contribution marginal	study; cf. Jonas (1997), Table 2.4-1][b] – *net import of biomass* (prior to production) may change to implicitly take care of changes in simulated future *biomass for energy*, which is not constrained to stay constant	increase in Austria's population [which, in turn, is connected with the amount of food required domestically; cf. Jonas (1997), Table 2.4-6] is not considered[c]	*pastures:* Austria's pastures as of 1990 combined with cattle grazing conditions as of 1950 and tuned to comply with net changes in animal density until 1990 – HUBI, the carbon balance model implemented, has not yet been tested aimed to reflect Austrian soil, climate and management conditions and, therefore, still reflects East German soil, climate and management conditions in its carbon exchange coefficients	fellings data from earlier forest inventories – the Leslie matrix formalism determining future forest growth employs simplifying conditions beyond those of constant future land use, the most important of which is the use of equal total mortalities throughout all age classes – the conversion factor used for calculating total tree biomass (in tC) from usable stem wood (in m^3 o.b.) is 0.28[d] – a CO_2-induced growth effect is not yet taken into account

[a] Conversion steps used here (and consistent with a conversion factor = 0.28; see also remark (d) to calculate wood carbon contents: from m^3 o.b. into m^3 u.b. by multiplying with 0.8; from m^3 u.b. into tC usable stem wood by multiplying with 0.20, respectively.

[b] Here it is hoped that this correction also holds for projections into the future.

[c] An increase in Austria's population is not taken into consideration here for several reasons: (1) the resulting effect in the model's response would be small; (2) a degree of model sophistication that does not yet exist would be assumed; and (3) consistency with the aggregated framework of Austria's wood sector.

[d] This conversion factor was used at the time of modeling. The revised conversion factor is 0.36.

Source: Jonas (1997)

Table 4. Comparison of the maximum change in Austria's net flow of carbon into the atmosphere between 1990–2050 (as shown by the ACBM for the Reference Scenario) with various uncertainties related to Austrian data on the basis of 1990. All values are given as absolute numbers.

Items to be compared	Value in 10^6 tC	Remarks
$\Delta Cnet_{max}$ [a]	2.9[b]	cf. Figures 4a & 4 b
Uncertainty related to soil carbon losses from Austria's arable land[c]	0.5	cf. Footnote 10
Total uncertainty in *Changes in Forest and Other Woody Biomass Stocks*[d, e]	1.4[f, g]	expressed as C in terms of total tree biomass cf. Jonas (1997; Appendix II)
Uncertainty in ΔGS (annual growing stock increment)[d, h]	1.5[g]	expressed as C in terms of total tree biomass cf. Jonas (1997; Section 2.2.3)
Uncertainty in domestic fellings and yield statistics[d, i]	1.9[g, j]	expressed as C in terms of total tree biomass cf. Jonas (1997; Table 2.2-6)
Statistical uncertainty related to Austria's use of fuel wood[k]	2.2[g, j]	expressed as C in terms of total tree biomass cf. Jonas (1997; Footnote 35)
Statistical uncertainty related to Austria's total biogenic decay flux (excl. human-induced carbon flows)[l]	3.3[j]	cf. Jonas (1997; Table 2.4-7)

a $\Delta Cnet_{max} = \max\{|Cnet(1990) - Cnet(t)|, t = 1990, 2000, \ldots, 2050\}$, as shown by the ACBM for the Reference Scenario (see Figures 4a, b).

b   In regard to the underlying conversion factor (0.28) used for calculating wood carbon contents and total tree biomass (in tC), see remark b to Table 2 and remark a to Table 3. Note that the revised conversion factor (which underlies the uncertainties reported in this table) is 0.36. However, one could expect that the choice of conversion factor has no significant influence on the change in the net flow of carbon into the atmosphere.

c   According to Dersch and Böhm (1997a, b), the decomposable carbon pool of Austria's arable land contained, on an average, 40.4 tC ha^{-1} in 1990 and revealed a mean loss rate of –0.24 tC ha^{-1}, compared to the figure of about –1.5% that results when employing the default values recommended by the revised 1996 IPCC Guidelines (see Footnote 10), that is, about –0.61 tC ha^{-1}. Thus, we are confronted with the peculiar case that the uncertainty, 0.37 tC ha^{-1} yr^{-1} (in absolute terms), is greater than the actual value based on measurements. Taking Austria's arable land as of 1990 into consideration (see Footnote 6), this uncertainty totals about $502 * 10^3$ tC.

d   Referring to Austria's exploitable forest. With reference to remark i, however, it must be noted that the annual yield statistics produced by the Austrian Central Statistical Office (Bittermann and Gerhold, 1995) also encompass trees outside of Austria's exploitable forest and outside of Austria's coppice forest.

e   Only taking account of moderate statistical uncertainties in completing Worksheet 5-1 (*Land Use Change and Forestry: Changes in Forest and Other Woody Biomass Stocks*); that is, uncertainties related (1) to the area of Austria's exploitable forest (±5%); (2) to its annual growth rate (±5%); and (3) to the commercial harvest (±3%) as reported by the Austrian Central Statistical Office (Bittermann and Gerhold, 1995). The uncertainty related to (1) is somewhat greater than that officially reported, for example in Austria's forest inventory (FMAF, 1995), but can be justified by our experience in constructing a consistent LUC database. For reasons of consistency, we used the same uncertainty for the annual growth rate. The uncertainty related to (3) is based on expert knowledge (R. Wakolbinger, 1995, 1996; personal communications). We recognize that there are other important uncertainties (for example, those related to determining the amount of phytomass) which, however, cannot be quantified with confidence. Therefore, they are not considered here.

f   Interpolated value. Austria's six forest inventories between 1952 and 1990 have been interpolated based on a 5-year averaging technique; for details see Schidler (1998). Austria's latest forest inventory (1992–1996) has not yet been taken into account. Therefore, the value reported here is an interpolated value for the year 1990, based on the values of previous years.

g   Based on a conversion factor of 0.36 to calculate wood carbon contents and total tree biomass (in tC).

h   The difference between: (1) measured annual growth rate and (2) the mean annual difference in measured growing stocks, based on the forest inventories 1981/85 and/or 1986/90, is $4,029 * 10^3$ m^3 o.b. yr^{-1}.

i   The difference in Austria's fellings and yield statistics [according to FMAF (1995), Schieler et al. (1996), and Bittermann and Gerhold (1995)] is $4,212 * 10^3$ m^3 u.b. yr^{-1}. To convert (m^3 u.b.) into (m^3 o.b.), see remark k below].

j   Mean value over the period 1989–1991.

k   With reference to Austria's use of fuel wood, the AIER (1996) statistics give a mean value of 88,090 TJ (= 65% of Austria's mean use of *other energy*) for 1989–1991, or $2,634 * 10^3$ tC [after multiplication by 29.9 tC (TJ)$^{-1}$, the emissions factor recommended by the IPCC (1995b, c) for wood]. The Austrian Central Statistical Office (Bittermann and Gerhold, 1995), on the other hand, gives a mean value of total fuel wood use of $5,354 * 10^3$ m^3 u.b. for 1989–1991, which converts to $6,693 * 10^3$ m^3 o.b. [applying a factor of 0.8^{-1} for converting (m^3 u.b.) into (m^3 o.b.)] and finally to $1,378 * 10^3$ tC as its wood carbon contents (in agreement with remark g). The difference, $1,256 * 10^3$ tC, is converted into total tree biomass (in tC) by applying a weighted expansion factor (in agreement with remark g).

l   Based on first-order top-down calculations and on a conversion factor of 0.28 to calculate wood carbon contents, Jonas (1997) reports a total biogenic decay flux of $3,031 * 10^3$ tC for Austria in 1990, excluding human-induced carbon fluxes due to food uptake. This value changes to about $3,631 * 10^3$ tC if wood carbon contents are corrected in agreement with remark g. Subtracting Austria's total

waste flux (derived bottom-up) according to its 2nd National Climate Report (FMEYF, 1997), which is 313 * 10^3 tC (here simply disregarding its origins and interpreting it entirely as a wood related decay flux), leaves an uncertainty of 3,318 * 10^3 tC.