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Interim Report **IR-01-064**

The Austrian Carbon Database (ACDb) Study — Overview

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Abstract

This is the final overview report of the Austrian Carbon Database (ACDb) Study, which pursues three main objectives: (1) to support the Austrian Carbon Balance Model (ACBM) II; (2) to internationalize the Austrian carbon analysis and to place Austria's carbon accounting within an international science and policy context focusing on the UN Framework Convention on Climate Change (FCCC); and (3) to provide good practice guidance in consideration of Full Carbon Accounting (FCA) rather than Partial Carbon Accounting (PCA).

The Study is divided into two phases, a deductive and an inductive research phase. The deductive research phase builds upon the theoretical insights gained during the ACDb Study and addresses Objective 2 (Internationalization). The inductive research phase builds upon the generalized experiences from working with uncertainties in building the ACDb and addresses Objectives 1 (ACBM II Support) and 3 (Good Practice Guidance).

The ACDb is a carbon consistent database for Austria that acknowledges FCA. It focuses on publicly available, including measured, data around 1990 and attributes special importance to the direct and transparent understanding of both first (mean values) and second statistical moments (uncertainties). The ACDb does not replace existing, officially agreed and widely accepted, Austrian databases but provides a thematically less detailed, however, carbon consistent standard that allows to quantify the uncertainties underlying these databases when using them in a wider (Austrian-integrated) context than traditionally done.

The focus of the Study is on conclusions that are generally valid and are not only specific for Austria. Based on our deductive and inductive research, we conclude that the Kyoto Protocol and the way national emissions are inventoried urgently need fundamental as well as methodological improvements, more than ever before.

Zusammenfassung

Dieser Übersichtsbericht schliesst die Studie *Austrian Carbon Database (ACDb)* ab, die drei Ziele verfolgt: (1) Das *Austrian Carbon Balance Model (ACBM) II* zu unterstützen; (2) das Fallbeispiel Österreich zu internationalisieren und die Kohlenstofferfassung Österreichs mit Blick auf das Klimarahmenabkommen der Vereinten Nationen in einen verallgemeinernden, wissenschaftlichen und politischen Kontext zu stellen; und (3) eine Anleitung für das Vorgehen bei einer vollständigen *(FCA: Full Carbon Accounting)* anstelle einer teilweisen Kohlenstofferfassung *(PCA: Partial Carbon Accounting)* bereit zu stellen.

Die Studie unterteilt sich in zwei Forschungsphasen, eine deduktive und eine induktive. Die deduktive Forschungsphase baut auf theoretischen Einsichten auf, die im Rahmen der Studie erarbeitet wurden, und verfolgt Ziel zwei (Internationalisierung). Die induktive Forschungsphase baut auf den verallgemeinerten Erfahrungen beim Arbeiten mit Unsicherheiten während der Erstellung des ACDb auf und verfolgt die Ziele eins (Unterstützung des ACBM II) und drei (Anleitung).

Das ACDb ist eine Kohlenstoff-konsistente Datenbank für Österreich, die die vollständige Erfassung von Kohlenstoff zum Anliegen hat. Sie konzentriert sich auf öffentlich verfügbare einschliesslich gemessene Daten um das Jahr 1990 und misst dem sowohl unmittelbaren als auch transparenten Verständnis von ersten (Mittelwerte) und zweiten statistischen Momenten (Unsicherheiten) besondere Bedeutung bei. Das ACDb ersetzt keine der existierenden österreichischen Datenbanken, bezüglich denen offizielles Einvernehmen herrscht und weitreichende Akzeptanz vorliegt, sondern stellt einen *Standard* bereit. Dieser ist thematisch nicht hoch-detailliert, dafür aber Kohlenstoff-konsistent, und gestattet die Quantifizierung von Unsicherheiten, die den einzelnen Datenbanken zugrunde liegen, wenn sie in einem grösseren (Österreich-integrierenden) Zusammenhang als bisher verwendet werden.

Der Schwerpunkt der Studie liegt auf Schlussfolgerungen, die allgemein gültig und nicht nur spezifisch für Österreich sind. Basierend auf unserer deduktiven und induktiven Forschung kommen wir zu dem Schluss, dass das Kyoto-Protokoll und die Art und Weise, wie nationale Emissionsinventuren vorgenommen werden, dringender als je zuvor fundamentaler als auch methodologischer Verbesserungen bedürfen.

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The Austrian Carbon Database (ACDb) Study — Overview

Matthias Jonas and Sten Nilsson

PART 1: Executive Summary

This is the final overview report of the Austrian Carbon Database (ACDb) Study, which was funded by the Austrian Federal Ministry of Education, Science and Culture and the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management. The Study pursues three main objectives:

1. Support of the Austrian Carbon Balance Model (ACBM) II: To provide a carbon consistent database, including uncertainties, for the complementary support of various ACBM II related tasks such as checking scenarios, testing sensitivities, quantifying uncertainties, providing for knowledge implementation through a user interface, etc.
2. Internationalization of the Austrian carbon analysis: To place Austria's carbon accounting within an international science and policy context focusing on the UN Framework Convention on Climate Change (FCCC).
3. Good practice guidance: To provide database-to-database consistency standards, determine and corroborate uncertainties underlying Austria's carbon budget, and complete data and uncertainties in consideration of Full Carbon Accounting (FCA) rather than Partial Carbon Accounting (PCA).

The Study is divided into two phases, a deductive and an inductive research phase. The deductive research phase builds upon the theoretical insights gained during the ACDb Study and addresses Objective 2 (Internationalization). The inductive research phase builds upon the generalized experiences from working with uncertainties in building the Austrian Carbon Database (ACDb) and addresses Objectives 1 (ACBM II Support) and 3 (Good Practice Guidance).

The ACDb was developed using Microsoft® Excel 2000. It is a carbon consistent database for Austria that acknowledges FCA. It focuses on publicly available, including measured, data around 1990. The ACDb complements missing data, to the extent appropriate, with the help of existing data but not, as a matter of principle, by applying diagnostic modeling.

The ACDb is organized into five modules: AGRO (Agriculture), CONSU/WASTE (Consumption and Waste), ENERGY (Energy), FOREST (Forestry), and PROD

(Production). These are intra-modularly linked but not inter-modularly (as a preventative measure to data corruption, etc.).

The ACDb attributes special importance to the direct and transparent understanding of both first (mean values) and second statistical moments (uncertainties), the balanced treatment of which requires agreement on an appropriate data aggregation level (thematic resolution). The ACDb grasps uncertainty with the help of a generic concept, which has already been applied by IIASA in a recent precursor study focusing on the full carbon account of Russia.

The ACDb deals only with existing data, which are available either from *one-sided statistics* (a complementary data set does not exist) or from *two-sided statistics* (a complementary data set exists). As a consequence, the term *uncertainty* — which we use exclusively — stands, in principle, for random error or (0.5 * uncertainty range). Soft knowledge is generally not considered. For the ACDb we chose the 68% confidence level (or its nonstandard statistical equivalent), because striving for a higher, purely mathematical confidence level cannot be justified physically as long as we have to cope with uncertainty ranges as a result of inconsistent or missing knowledge in realizing full carbon accounts.

The ACDb Study does not follow the objective of replacing existing, officially agreed and widely accepted, Austrian databases but to provide a thematically less detailed, however, carbon consistent standard that allows to quantify the uncertainties underlying these databases when using them in a wider (Austrian-integrated) context than traditionally done.

As mentioned above, our Study produces a full carbon account of Austria, including uncertainties, centering around 1990. However, our focus is on conclusions that are generally valid and are not only specific for Austria. Based on our deductive and inductive research, we conclude that the Kyoto Protocol and the way in which national emissions are inventoried urgently need fundamental as well as methodological improvements, more than ever before. Our deductive research directly leads us to the following five straightforward conclusions in order to guide the Protocol towards success:

1. A robust FCA system [embedded into a proper *Full Greenhouse Gas* Accounting (FGA) system], which permits the quantification of uncertainties within this wider context, is required. Only such an accounting system can form a solid basis for accounting greenhouse gas emissions and removals under the Kyoto Protocol.
2. The biosphere must be treated as one system and must not be split into a *Kyoto* and a *non-Kyoto biosphere*.
3. The Intergovernmental Panel on Climate Change (IPCC) uncertainty concept, which is defined with regard to two pre-defined points in time but disregards how the signal evolves dynamically in time, must be replaced by a verification concept that is sufficient in terms of temporal verification.
4. Bifurcated rules (actually, Protocols) are needed that treat the more easily verified fluxes (fossil fuel CO_2, especially) differently from those that are more uncertain (notably, CO_2 sinks).

5. An understanding of what the environmental criteria under the Kyoto Protocol should be must be developed. Environmental objectives (e.g., sustainability criteria) need to be introduced as a *condicio sine qua non* before economic measures are permitted to take effect.

Our inductive research with reference to national emission inventories complements conclusions 1 and 4 above. With respect to conclusion 1, our additional conclusions are as follows:

- The generation of a full carbon (or greenhouse gas) account for a country, which — ultimately — should be based on Material Flow Analysis (MFA) because of its more direct link to the country's socioeconomic activities, is not an easy task but needs to be tackled. An instructional manual with clear guidelines on how to accomplish this is not available and it will take some time until this will be the case. Major data limitations and inconsistencies will occur, a situation which we consider typical for many countries.
- We recommend the application of relative uncertainty classes as a common good practice measure. They constitute a robust means to get an effective grip on uncertainties. In light of the aforementioned data limitations and inconsistencies, the reporting of exact relative uncertainties is not justified.
- To assess the uncertainties of national emission inventories, we suggest — in addition to applying Monte Carlo analysis for scientific safeguard reasons — a simplified calculational procedure, which makes use of the law of uncertainty propagation as well as arising approximations, but which is more accessible to external verification.
- Austria is a *data-rich* country, making even *two-sided* statistics available in a number of cases. These are most interesting because they generally disagree, offering the rare possibility to expert review teams of scrutinizing the quality of their work and asking themselves what they could not adequately review if countries provided them with only *one-sided* statistics. We suspect that, in the short-term, increased data richness will uncover more of these predicaments rather than confirming existing understanding.
- PCA, as under the Revised 1996 IPCC Greenhouse Gas Guidelines or the Kyoto Protocol, does not ensure that the physical law of conservation of matter is rigorously preserved in deriving biospheric sink (or source) strengths. Compliance with this physical boundary condition can lead to a greater uncertainty to be considered in the accounting. This shortcoming needs to be remedied. The accounting of biospheric sink (or source) strengths as under the Kyoto Protocol is least trustworthy, revealing uncertainties potentially greater than 100% and, thus, implications that may be crucial with respect to the implementation of Articles 3.3 and 3.4 of the Protocol.

With respect to conclusion 4, our additional conclusions are as follows:

- The consideration of forest (as well as other biospheric) sink strengths in the total national CO_2 emissions increases the overall relative uncertainty of the combined CO_2 emissions (potentially also in terms of classes depending on the magnitude of the sink strength). A greater relative uncertainty induces a greater verification time (VT), which is the time until a signal begins to outstrip its underlying uncertainty.

- Superimposing the highly uncertain emissions of the non-CO_2 greenhouse gases with the less uncertain CO_2 emissions can also induce the aforementioned effect. The overall emissions carry a greater relative uncertainty and thus result in a greater VT.
- The ENERGY module's CO_2 emissions reveal — as the only module of the ACDb — the smallest relative uncertainty class, a situation which we consider typical for many countries. In combination with the two aforementioned conclusions, this supports our request for bifurcated rules (actually, Protocols) that are needed to treat the more easily verified fluxes differently from those that are more uncertain.

PART 2: Introduction and Overview

2.1 Introduction

2.1.1 Scope of the Report

This is the final report of the Austrian Carbon Database (ACDb) Study. It presents the general overview on the Study. It gives emphasis to the epistemological aspects of the research performed, the results achieved, and their consequences. All results are contained in a CD. The technical report, which describes the mathematical details that underlie the database results, is presented separately.

2.1.2 Background

The ACDb Study commenced in June 1999 and has been reported intermittently throughout the research.[1] It was funded by the Austrian Federal Ministry of Education, Science and Culture and the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management.

2.1.3 Rationale

The ACDb Study grew from a number of scientific questions that were perceived as sufficiently substantial to be addressed separately:

1. The study titled *Systems Analytical Assessment of Austria's Carbon Balance,* which was completed in December 1997 (Phase I; hereafter called *ACBM I*), stated that the availability and consistency of data pose a, if not the, major problem in modeling Austria's carbon balance dynamically in a synoptical rather than intradisciplinary fashion. The relevant scientific question was how to give additional and complementary data support to the follow-up study, the Austrian Carbon Balance Model (Phase II; hereafter *ACBM II*) project.

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[1] February 2000: Interim Report.
March 2000: ACBM II–ACDb Workshop at the Austrian Federal Ministry of Education, Science and Culture.
July 2000: ACBM Workshop at the Austrian Federal Ministry of Education, Science and Culture.
December 2000: Lecture delivered at the Austrian Academy of Sciences.

2. The ACBM I study also addressed the important issue of data uncertainty (particularly related to Austria's carbon stocks), recognizing that the comparative advantages of any successor model would dwindle if it did not tackle this issue. However, experience on how to exactly do this was scarce, also internationally, and only began to become available in combination with IIASA's parallel work on Russia's full carbon account at that time.
3. In addition to the direct benefit in the form of data support, it was felt that more *international* expertise was needed in regard to the accounting and reporting of national (including Austria's) carbon emissions and removals under the UN FCCC. It was argued that this could be best achieved if the entire carbon expertise of more than one country would be available, which would permit making general conclusions. Again, however, it was not clear in detail how to achieve this; ideas at that time were vague and did not go beyond the mere comparison of national carbon accounts.

2.1.4 Previous and Ongoing Research

As a result of the Kyoto policy process, countless carbon research activities are carried out worldwide (with respect to Austria, see, e.g., Chapter 8 in Austria's forthcoming Third National Climate Report), an increasing number of them focusing on uncertainty. We refer to many of them in the course of our Study.

Here, we use a set of principal descriptors, namely *national-scale* in combination with *Full Carbon* (or *Greenhouse Gas*) *Accounting* (FCA or FGA, respectively) and *Partial Carbon* (or *Greenhouse Gas*) *Accounting* (PCA or PGA, respectively), to discriminate between the different activities and structure them.[2] Other useful descriptors to characterize the activities are:

DC Data consistency (under PCA or PGA, and FCA conditions);

M Modeling;

S Sensitivity;

$U_{Account}$ Uncertainty that underlies the carbon [or greenhouse gas (GHG)] account of a country at a particular point in time;[3]

U_{Model} Uncertainty that underlies the model-projected net carbon (or GHG) emissions of a country in time;[4] and

VT Verification time.

(see also Table 1).

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[2] For a definition of FCA see, e.g., Steffen *et al.* (1998), Jonas *et al.* (1999a, b; 2000) or Nilsson *et al.* (2000a, b).

[3] $U_{Account}$ is specified in Section 3.1.2 more precisely as the account's level or total uncertainty.

[4] U_{Model} and $U_{Account}$ are different, as will be explained in Section 2.2.2.

Table 1: Setting of the ACDb Study in Austria.

FCA: Austria	FCA: Austria	PGA (FF+LULUCF): Austria	FCA: Russia	Time	Some Events Relevant to Austria or the ACDb Study
ACBM I (ARCS) **DC** **M** ✔ **S** **U_Account** **U_Model** **VT**		**Official Reporting (Continuously)** (FEA) ↓		**1996**	
				1997	2nd NCR Kyoto Protocol
				1998	
ACBM II (ARCS, IIE, JRG) **DC** (✔) **M** ✔ **S** ✔ **U_Account** **U_Model** ✔ **VT**	**ACDb** (IIASA) **DC** ✔ **M** **S** **U_Account** ✔ **U_Model** **VT** (✔)	**DC** ✔ **M (FF)** ✔ **S** **U_Account** ✔ **U_Model** **VT**	**Russian Study** (IIASA) **DC** ✔ **M** **S** **U_Account** ✔ **U_Model** **VT** (✔)	**1999**	
				2000	COP-6 (First Part)
				2001	COP-6 (Second Part) 3rd NCR, COP-7

Completed in December 1997, the ACBM I study focused on **FCA** and **M** (Jonas, 1997; Orthofer, 1997). As one of the first of its kind, it aimed at modeling Austria's full carbon balance dynamically in a synoptical rather than intradisciplinary fashion and provided grounds for two follow-up projects, the ACBM II project and the ACDb Study.

The main objective of the ACBM II, among other things, is to follow up **FCA** and **M** and to perform **S** and $\mathbf{U_{Model}}$ investigations in a more comprehensive fashion than realized by the ACBM I (Orthofer *et al.,* 2000). By way of contrast, the ACDb Study focuses on **DC** and $\mathbf{U_{Account}}$ of measured data (including data derived from measurements), in consideration of **FCA**.[5] Thus, these two studies complement each other.

Another concern of the ACDb Study already mentioned is to internationalize Austria's carbon balance, i.e., to place it within an international science and policy context focusing on the UN FCCC. This is achieved (as will be explained in the course of the Study) by introducing the notion of verification time (**VT**). The VT is the time until a signal begins to outstrip its underlying uncertainty (see Section 3.1.2). It permits to discriminate between systems revealing different dynamical characteristics, e.g., to compare the net GHG emissions of countries, in consideration of their uncertainties, and to quantify the verification regimes under which the countries operate.

[IIASA's Forestry Project presently makes an attempt to study the VT concept in greater depth, in collaboration with a number of other countries. The issues looked into are **PCA (FF)**, **DC**, and $\mathbf{U_{Account}}$ and **VT** in the presence of non-linear (higher-order) emission signals, as they are typical for the Annex I countries under the Kyoto Protocol.[6]]

The incentive for realizing the VT concept came from the *Full Carbon Account for Russia* study (Nilsson *et al.*, 2000a), which was carried out by IIASA's Forestry Project in parallel to the ACDb Study. The Russian study focuses on **FCA**, **DC**, $\mathbf{U_{Account}}$ and simplified (linear) **VT** calculations. However, $\mathbf{U_{Account}}$ was recognized only in the advanced state of the study as a quantity of paramount importance, while the ACDb Study paid equal attention to the first (net emissions) and second statistical moments ($U_{Account}$) from the very beginning. (This difference was determinative for the course of the ACDb Study and will be discussed later.) Presently, IIASA's Russian study is extended to include all GHGs or groups of gases mentioned under the Kyoto Protocol (FCCC, 1998).

In accordance with its tasks, Austria's Federal Environment Agency (FEA) focused — with the support of various Austrian institutions — primarily on **PGA (FF+LULUCF)**,

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[5] It must be mentioned that, as a consequence of the timing of the ACBM II and the ACDb studies, the ACBM II teams had to generate their own data and to also look into questions related to data consistency — however, only to the extent that serves the purpose of the model.

[6] **FF** refers to a country's anthropogenic carbon emissions (fossil fuel system), excluding those resulting from LULUCF (see Footnote 7).

DC, and **M (FF)**.[7] However, recently FEA also pays increasing attention to $\mathbf{U_{Account}}$. Two of its studies, Weiss *et al.* (2000) and Winiwarter and Orthofer (2000) (see also Winiwarter and Rypdal, 2001), are noteworthy and will be discussed and also taken advantage of in this Study. They form the basis for the uncertainties that are associated with Austria's GHG inventory.

This trend towards treating uncertainties more rigorously **—** that is, $\mathbf{U_{Account}}$ in consideration of **PGA (FF)** or **PGA (FF+LULUCF) —** and including them in national GHG inventories can also be observed internationally. In the wake of publishing the IPCC Report titled *Good Practice Guidance and Uncertainty Management in Greenhouse Gas Inventories* (IPCC, 2000a), also countries other than Austria such as Great Britain, Norway, The Netherlands, and Poland have made, or will soon make, their uncertainty assessments available (Charles *et al.*, 1998; Rypdal and Zang, 2000; van Amstel *et al.*, 2000; Gawin, 2002). More countries are expected to follow.

In conclusion, it is of importance to note that, so far, only two national-scale studies exist, IIASA's Russian study and the ACDb Study, that apply a **FCA** approach and look into $\mathbf{U_{Account}}$; and only two national-scale studies, the ACDb Study and the ACBM II study, permitting the investigation of $\mathbf{U_{Account}}$ and $\mathbf{U_{Model}}$ in parallel, in consideration of **FCA**.

2.1.5 Objectives

The ACDb Study pursues the following three main objectives:

1. *Support of the ACBM II:*

   To provide a carbon consistent database, including uncertainties, for the complementary support of various ACBM II related tasks such as checking scenarios, testing sensitivities, quantifying uncertainties, providing for knowledge implementation through a user interface, etc.

2. *Internationalization of the Austrian carbon analysis:*

   To place Austria's carbon accounting within an international science and policy context focusing on the UN FCCC.

3. *Good practice guidance:*

   To provide database-to-database consistency standards, determine and corroborate uncertainties underlying Austria's carbon budget, and complete data and uncertainties in consideration of FCA rather than PCA.

The ACDb Study does not follow the objective of replacing existing, officially agreed and widely accepted Austrian databases [e.g., of Austria's Federal Environment Agency (FEA) or Austria's Federal Forest Research Centre (FFRC)], but to provide a less detailed, however, carbon consistent standard that allows to quantify the uncertainties underlying these databases when using them in a wider (Austrian-integrated) context

[7] **LULUCF** refers to a country's carbon emissions and removals resulting from its land use, land-use change and forestry, in accordance with the IPCC Guidelines (IPCC, 1997a, b, c).

than traditionally done. The ACDb does not complement missing data, as a matter of principle, by applying diagnostic modeling.

2.1.6 Conditional Framework

From its outset, the ACDb Study was requested to fulfill three principal conditions, viz., that:

1. The Study is carried out in close collaboration with and provides comprehensive data support to the ACBM II teams.
2. The Study is carried out in close cooperation with Austrian governmental institutions that are involved in the Kyoto policy process to ensure maximal use of the Study in this process.
3. The results of the Study are freely available to Austrian collaborators and stakeholders, and other experts and researchers, who are interested in using them.

It is particularly the first condition that will give rise to a fundamental discussion on the level of detail, up to which first (net emissions) and second statistical moments ($U_{Account}$) can and should be assembled in the ACDb Study (see Section 4.1.2).

2.2 Overview

2.2.1 Guide Through the Study

The ACDb Study can be divided into two complementary phases, a deductive (Part 3) and an inductive research phase (Part 4) (see Figure 1). Each phase draws on a number of publications, primarily IIASA Interim Reports. The deductive research phase builds upon the theoretical insights gained during the ACDb Study and addresses Objective 2 (Internationalization). The inductive research phase builds upon the generalized experiences from working with uncertainties in building the database and addresses Objectives 1 (ACBM II Support) and 3 (Good Practice Guidance).

Parts 3 and 4 take the reader through the entire ACDb Study. They put relevant publications into context and ensure that the overview is preserved. They give emphasis to the epistemological aspects of the research performed, the results achieved, and their consequences. The overall conclusions, together with important research challenges ahead of us, are provided in Part 5. As mentioned before, the mathematical details that particularly underlie the results of the database are described in a technical report that is presented separately.

2.2.2 The Applied Uncertainty Concept

In the Study, we make a difference between $U_{Account}$ and U_{Model} (see Figure 2). To these ends, it is sufficient to use the term *model* in a prognostic context that relates to a possible future.[8] $U_{Account}$ reflects our real diagnostic capabilities, that is, the uncertainty, which underlies our past as well as our current observations (accounting) and which we will have to cope with in reality at some time in the future (e.g., commitment year). $U_{Account}$ may decrease with increasing knowledge. By way of contrast, U_{Model} always increases due to the model's decreasing prognostic capabilities with time.

The interrelation between U_{Model} and $U_{Account}$ can be made clear with the help of the notion of an *ideal* model. An ideal model reflects reality perfectly during the model's start-up (diagnostic) phase, that is, $U_{Account}$ (= U_{Model}) is the uncertainty, which underlies the model's initial data. However, in practice as well as during their prognostic mode, models are generally not able to reproduce $U_{Account}$ for a number of reasons. In addition to the models' decreasing prognostic capabilities with time, another important reason is that model builders typically fall under the purview of complexity, instead of simplification. In their models they tend to resolve more detailed first statistical moments (mean values), the more complex the reality appears that they wish to reflect. However, the consideration of uncertainties requires the opposite, that is, to simplify models, ideally to a level which permits to treat uncertainties as statistically independent (or as statistically independent as possible) (see also Section 4.1.2).

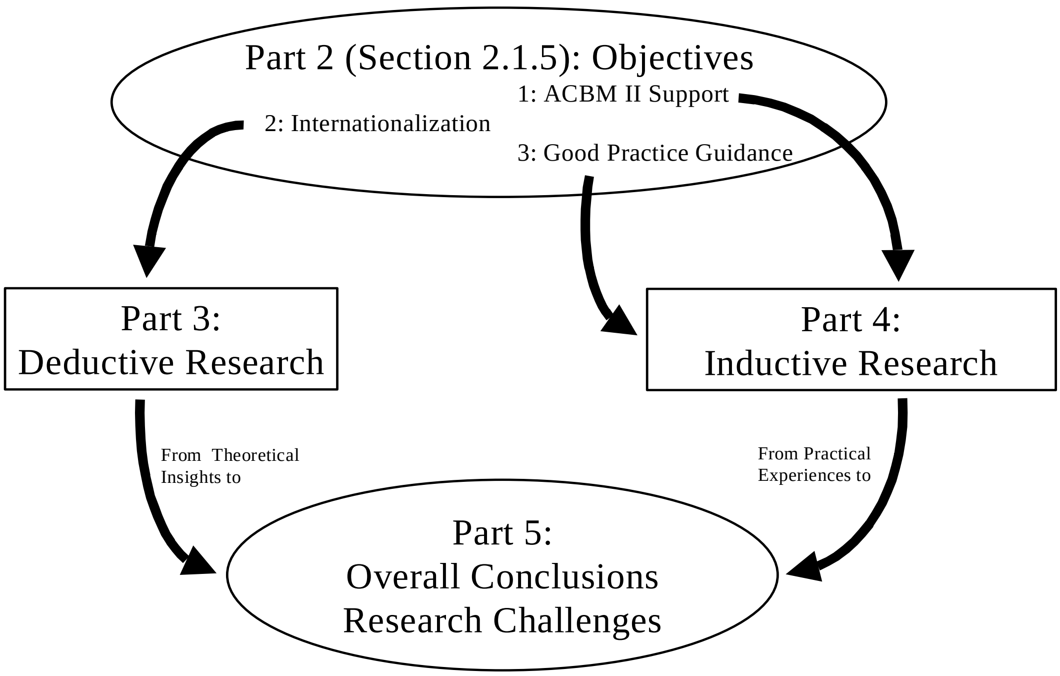

Figure 1: Guide through the ACDb Study.

[8] We acknowledge that a model can also be run in a diagnostic mode, e.g., to complement missing data (which the ACDb does not do).

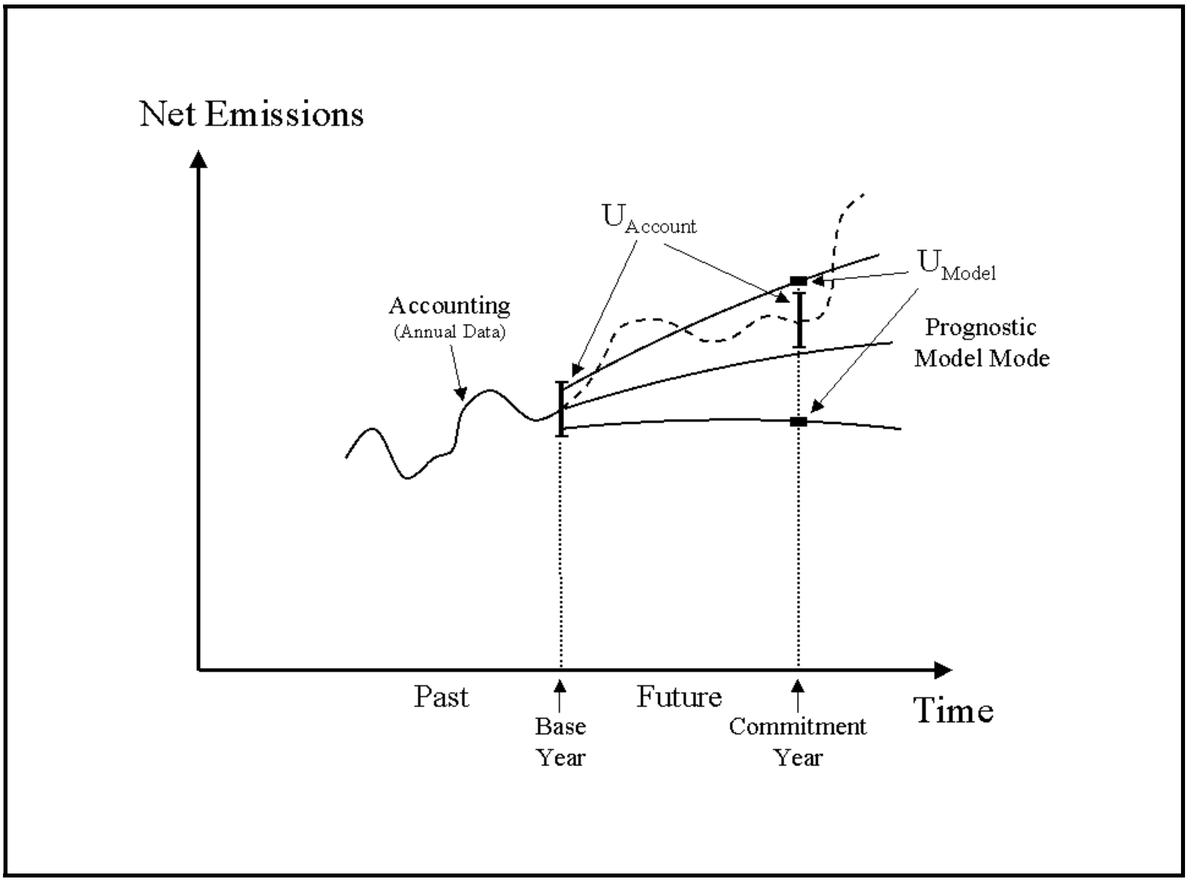

Figure 2: Simplified illustration featuring accounting versus prognostic modeling. The accounting may happen annually, while the results of a model can, at best, only be interpreted to reflect a multi-year period that excludes singular stochastic events (although the model may operate with a time step of ≤ 1 year). For simplification, we let $U_{Account}$ stay constant over time.

Verification under the Kyoto Protocol requires knowledge of $U_{Account}$, not U_{Model}, and the dynamics that underlies an emission signal (see Section 3.1.2), while model scenarios can be helpful in deciding whether short-term actions, e.g., by policy makers, comply with long-term desirable futures. By *emission signal* we mean the net flux into the atmosphere, which can be derived from measurements (and/or with the help of a diagnostic model). At present, the scientific communities that are associated with the accounting of GHG emissions under the Kyoto Protocol, foremost those which assisted in writing the IPCC *Good Practice Guidance and Uncertainty Management in Greenhouse Gas Inventories* Report (IPCC, 2000a; FCCC, 2001c, d), focus solely on $U_{Account}$. They consider this uncertainty with regard to two predefined points in time (what we call the two-points-in-time IPCC uncertainty concept), but disregard the physical quantity time itself, that is, how the emission signal evolves between the two identified time points.[9]

[9] In addition to temporal verification on sub-global scales, the option also exists of verifying bottom up net emission estimates by top down atmospheric net flux (or storage) measurements, which may overlap

We encountered a great number of publications that refer to $U_{Account}$ and U_{Model} and attempt to structure and classify them generically in more detail. We refer to many of them, including the aforementioned IPCC Report and the guidance paper by Moss and Schneider (2000) on uncertainty for the IPCC Third Assessment Report, in Shvidenko *et al.* (1996), Jonas *et al.* (1999a), Nilsson *et al.* (2000a, 2002) and Obersteiner *et al.* (2000c). A similar and noteworthy attempt has been done most recently by Rotmans and van Asselt (2001) in order to increase the use and application of integrated models. However, we have not found any literature that addresses the problem of verification under the Kyoto Protocol in a more fundamental way that also considers the dynamics of signals.

Before addressing the problem of signal dynamics in more detail (which we do in Part 3), there is another problem to overcome. It must be ensured that $U_{Account}$ fulfills the condition of consistency, as required for any system or set of systems under FCA. This is achieved by employing the IIASA uncertainty concept (see Figure 3), which is presented and discussed in more detail in Nilsson *et al.* (2000a) (see also Geisler and Jonas, 2001). This concept acknowledges that both available knowledge and lack of knowledge exists when accounting net carbon emissions. Available knowledge can be hard or soft, while lack of knowledge can be interpreted as the difference between an accepted and the (unknown) true value due to unknown biases. (The term *value* may be understood, e.g., as the net atmospheric carbon emissions of a country. Only a measurement device, located in the atmosphere, which would measure the country's net carbon flux into the atmosphere, would permit cross-checking the ground-based experts' estimate and thus the elimination of unknown biases.) Random errors and systematic errors (the latter are also called determinate errors or simply biases, while we prefer *quantified systematic error* or *measured biases*) are typically used to evaluate hard as well as soft knowledge in terms of uncertainty. By way of contrast, lack of knowledge can only be addressed in a way that is necessary but not sufficient. This is done, as shown in Figure 3, by defining an uncertainty range that encompasses each of the two measured biases plus each of the two standard deviations representing the random errors of the two depicted measurement sets.

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each other spatially (e.g., Jonas *et al.*, 1999a; Nabuurs *et al.*, 1999; Post *et al.*, 2001; Smith, 2001). However, this option is not discussed here further because of three important reasons (see also Section 3.1.5.2): (1) discerning a signal of change from the noise of uncertain gross fluxes can take decades. Gross fluxes are large and notoriously uncertain and variable (e.g., Nilsson *et al.*, 2001); (2) it is almost impossible to trace net emissions identified on *larger* spatial scales back to individual sources/sinks or source/sink categories (here: *Kyoto* and *non-Kyoto LULUCF sources/sinks*) if their net emissions do not contain some sort of *fingerprint* that characterizes them (IPCC, 2000a; Jonas *et al.*, 2000); and (3) the amount of Kyoto eligible LULUCF activities must be expected to be considerable. This alone poses severe practical constraints on the use of such bottom up–top down cross-checks on *smaller* sub-global scales, which cannot be commonly performed (Jonas *et al.*, 2000; see also Martin *et al.*, 2001; Smith, 2001).

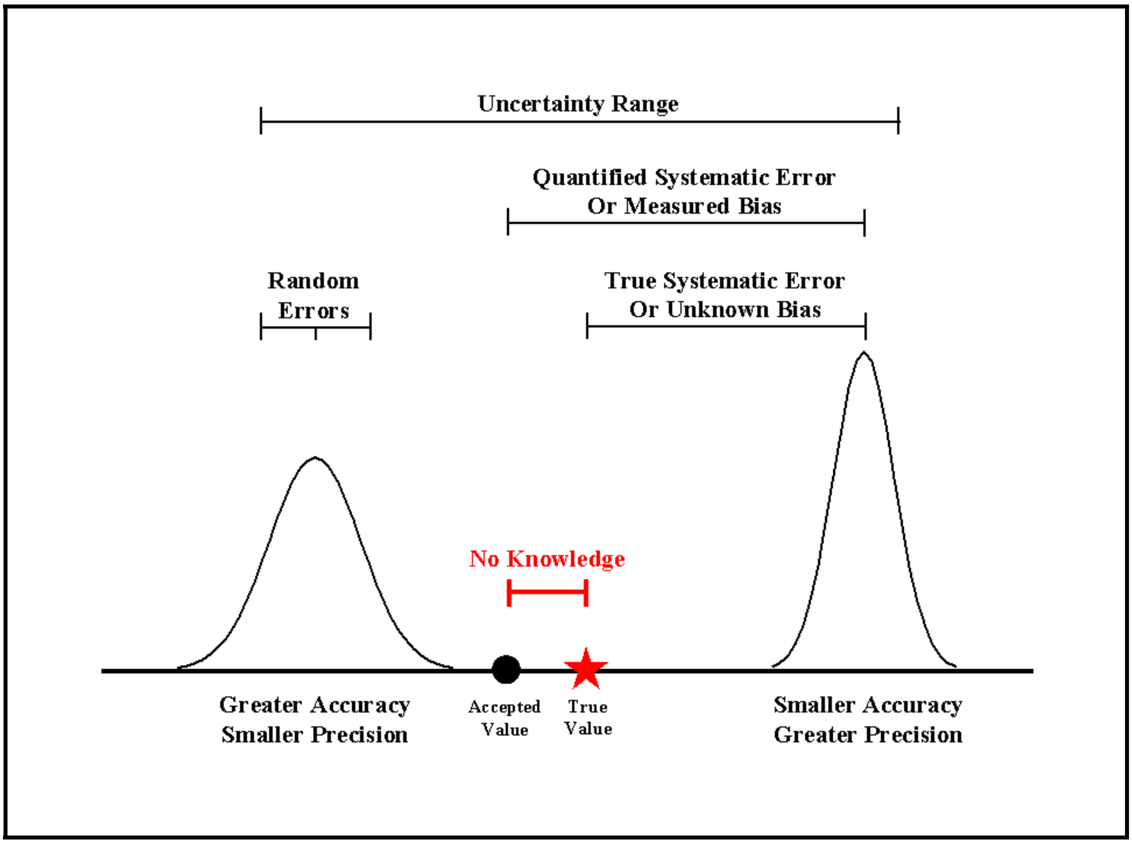

Figure 3: The IIASA uncertainty concept: A hypothetical uncertainty range for two sets of measurements of the same phenomenon (individual variable) (see Nilsson *et al.*, 2000a). Here, the uncertainty range encompasses each of the two measured biases plus each of the two standard deviations representing the random errors of the underlying measurement sets.

In the Study, we use the term *uncertainty* exclusively, in accordance with the International Organization for Standardization (ISO, 1995) (see also Taylor and Kuyatt, 1994; NIST, 2001). Since the Study only deals with existing data, which are available either from *one-sided statistics* (a complementary data set does not exist) or from *two-sided statistics* (a complemenary data set exists)[10], the term *uncertainty* stands, in principle, for random error or (0.5 * uncertainty range). Soft knowledge is generally not dealt with (thus, measured biases are not considered).

[10] Here, our terminology is determined by the law of conservation of matter (see also Jonas *et al.*, 1999a; Geisler and Jonas, 2001).

PART 3: Deductive Research

Part 3 takes the reader through our deductive research phase, which covers Objective 2 (Internationalization) of the ACDb Study. It individually refers to the theoretical insights of a number of relevant studies that we have carried out in the context of our research on FCA (Section 3.1), summarizing their results (Section 3.2) and drawing conclusions (Section 3.3).

With the help of the various studies, Section 3.1 addresses four central issues from different perspectives. These are FCA, verification, systems revealing different dynamics and uncertainties, and Kyoto eligible mechanisms. The definition of verification used here as a reference is taken from IPCC (2000a: Annex 3). It is sufficient as it specifies verification towards the intended purpose of the Kyoto Protocol, which can only be done from an atmospheric point of view: *What matters is what the atmosphere sees!*

Section 3.2 summarizes the results of the studies that were drawn at the time of writing, while Section 3.3 outlines the conclusions in consideration of these results, but taking the most recent Kyoto policy decisions into account.

The outstanding research challenges are identified in Section 5.2, together with those from Part 4.

3.1 Theoretical Insights

3.1.1 IIASA Interim Report IR-99-025

Full Carbon Accounting and the Kyoto Protocol: A Systems-Analytical View
By: M. Jonas, S. Nilsson, A. Shvidenko, V. Stolbovoi, M. Gluck, M. Obersteiner and A. Öskog

In this report, the authors (Jonas *et al.*, 1999a) analyzed four crucial issues that were considered relevant to, but not appropriately taken into account by, the Kyoto Protocol at the time of writing. The issues relate to (1) whether the Revised 1996 GHG Guidelines of the IPCC (1997a, b, c) can serve as the main carbon (GHG) accounting system and thus serve as a legal basis of compliance for the Kyoto Protocol; (2) FCA; (3) establishment of 1990 baselines and post-1990 baseline scenarios for LULUCF activities; and (4) accounting for uncertainty.

The first issue (accounting system and basis of compliance) was first raised by Bolin (1998), the former chairman of the IPCC but is no longer discussed intensively — although it is closely associated with the still vexing second issue (FCA). Issues three (baselines and scenarios) and four (uncertainty) are believed to have been solved — at least for Article 3.4 activities under the Kyoto Protocol — by political decision during the Sixth Session of the Conference of the Parties (2^{nd} Part) (COP 6/II) to the UN FCCC (FCCC, 2001a, b, f) (see also Appendix 2).

With respect to the second (FCA) and the fourth issue (uncertainty), the issues of interest to the ACDb Study, the authors stated:

- "*The scientific challenge of FCA.* Owing to the fact that the Protocol does not adhere to the scientific challenge of FCA, it reveals a number of serious, not purely technical, scientific and methodological issues, which it would not do otherwise… Complying with the concept of FCA would cover these issues, with the exception of those that go beyond carbon emission concerns — pointing to the more general problem of inadequate coordination of global environmental protection. The objectives and catalogues of measures set up by the individual conventions and other international agreements need to be harmonized more rigorously. "
- "*The scientific challenge of accounting for uncertainty.* This scientific challenge has not yet been widely addressed… by the scientific community. The uncertainty issue may have played a role in developing the Kyoto Protocol, but this is insufficiently reflected in the text of the Protocol. The crucial question whether the uncertainties in estimating carbon fluxes associated with land-use change and forestry are so large as to threaten the compliance process cannot yet be answered with sufficient rigor. First research findings indicate that the individual and combined effect of these uncertainties are not yet understood… and may pose major difficulties in making the Protocol operational…"

It is these two issues that receive closer attention in the following reports.

3.1.2 IIASA Interim Report IR-99-062

Verification Times Underlying the Kyoto Protocol: Global Benchmark Calculations
By: M. Jonas, S. Nilsson, M. Obersteiner, M. Gluck and Y. Ermoliev

In this IIASA Interim Report, the authors (Jonas *et al.*, 1999b) introduced the VT concept. This concept requires that the absolute change in net carbon emissions, $\left|\Delta F_{net}(t_2)\right|$ at time t_2 (e.g., commitment year), with reference to time t_1 (e.g., base year) ($t_1 < t_2$), is greater than the uncertainty in the net carbon emissions at time t_2. Mathematically, this condition is expressed as:

$$\left|\Delta F_{net}(t_2)\right| > \varepsilon(t_2) \;.^{11} \qquad (4\text{-}1)$$

[11] Here, the authors expressed the uncertainty (ε) in absolute terms. However, without restricting generality, the uncertainty can also be linked to the absolute change in net carbon emissions $\left(\left|\frac{\Delta F_{net}}{dt}\right|\right)_{t_1}$ and expressed in relative terms, as it is also commonly done. This, in turn, would evoke a discussion on the dependence of ε on $\left|\Delta F_{net}\right|$, which would come too early at this point in time, but can be postponed for good physical reasons (see below) for the time being. This discussion is covered in an ongoing IIASA study, which is specifically devoted to the investigation of VTs (in this context see also Dachuk, 2002; Gusti and Jęda, 2002).

Under the assumption that first-order (i.e., linear) approximations are applicable (we take a glimpse of the nonlinear case in Section 3.1.4), we obtain:

$$\left|\frac{dF_{net}}{dt}\right|_{t_1} \Delta t > \varepsilon(t_1) + \left(\frac{d\varepsilon}{dt}\right)_{t_1} \Delta t \quad . \tag{4-2}$$

Rearranging Equation (4-2), we obtain an expression for the verification time (Δt), that is, the time required for an emission change to outstrip its underlying uncertainty:

$$\Delta t > \frac{\varepsilon(t_1)}{\left|\frac{dF_{net}}{dt}\right|_{t_1} - \left(\frac{d\varepsilon}{dt}\right)_{t_1}} \ , \tag{4-3}$$

where

$$\left|\frac{dF_{net}}{dt}\right|_{t_1} > \left(\frac{d\varepsilon}{dt}\right)_{t_1} \tag{4-4}$$

and $\pm\varepsilon$ (defined via F^+ and F^-, the upper and lower uncertainty limits of the net carbon emissions) is the uncertainty in F_{net}. This is illustrated graphically in Figure 4.

In combination with this definition, a number of physical issues arise, which were discussed by the authors, not necessarily in this, but also in later reports. Here, we refer to four of them, including an example, and mention others below in the context of the respective IIASA reports.

3.1.2.1 Issue 1

> *The decision whether or not the net emissions of a country differ detectably from its committed target requires the consideration of the past dynamics of the country's emission signal.*[12]

This is illustrated in Figure 5, which shows a simplified (linear) representation of the VT concept. The figure also reflects the two-points-in-time IPCC uncertainty concept, that is, the two uncertainties, which are currently discussed in accounting carbon under the Kyoto Protocol (IPCC, 2000a, b): level (or total) uncertainty, U_{Level} (which is identical to $U_{Account}$ first introduced in Section 2.1.4), and trend uncertainty, U_{Trend} (which reflects the uncertainty of the difference in net emissions between two years). For the following discussion, the knowledge of these two uncertainties suffices (for

[12] Here, we refer to the spatial scale of countries, because it is the spatial scale that is requested for reporting carbon emissions and removals under the Kyoto Protocol. We discuss smaller spatial scales in Section 3.1.5.2 in the context of IR-00-061 (Jonas *et al.*, 2000).

additional details see IPCC, 2000a; Jonas *et al.*, 2000). They may give rise to the following conceivable dispute:

Case 1: A country may succeed in reducing its net emissions between time t_1 and time t_2. This reduction may be interpreted, e.g., by applying the concept of subtracting mean values. The uncertainty that is associated with this technique is called trend uncertainty. The trend uncertainty may or may not be greater than a country's quantified emission limitation or reduction objective (e.g., Rypdal and Zhang, 2000). Here, let us assume that the committed reduction target of the country falls outside the trend uncertainty. Consequently, the country may be evaluated as not having reached its reduction target.

Case 2: The country may dislike this interpretation and argue differently, e.g., by employing the notion of level uncertainties that underlie its emissions at t_1 and t_2: "The reduction objective falls within the level uncertainty range. Therefore, the conclusion of no-compliance cannot be supported."

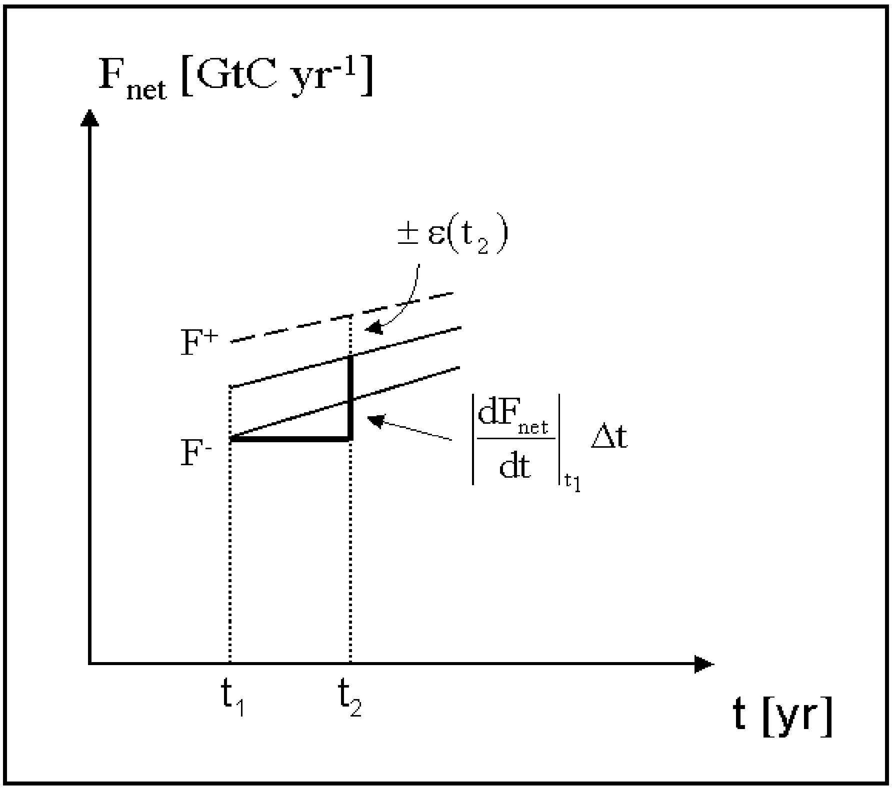

Figure 4: Simplified (linear) graphical representation of Equation (4-1) for increasing net carbon emissions (F_{net}) and a decrease in their uncertainty ($\pm\varepsilon$).

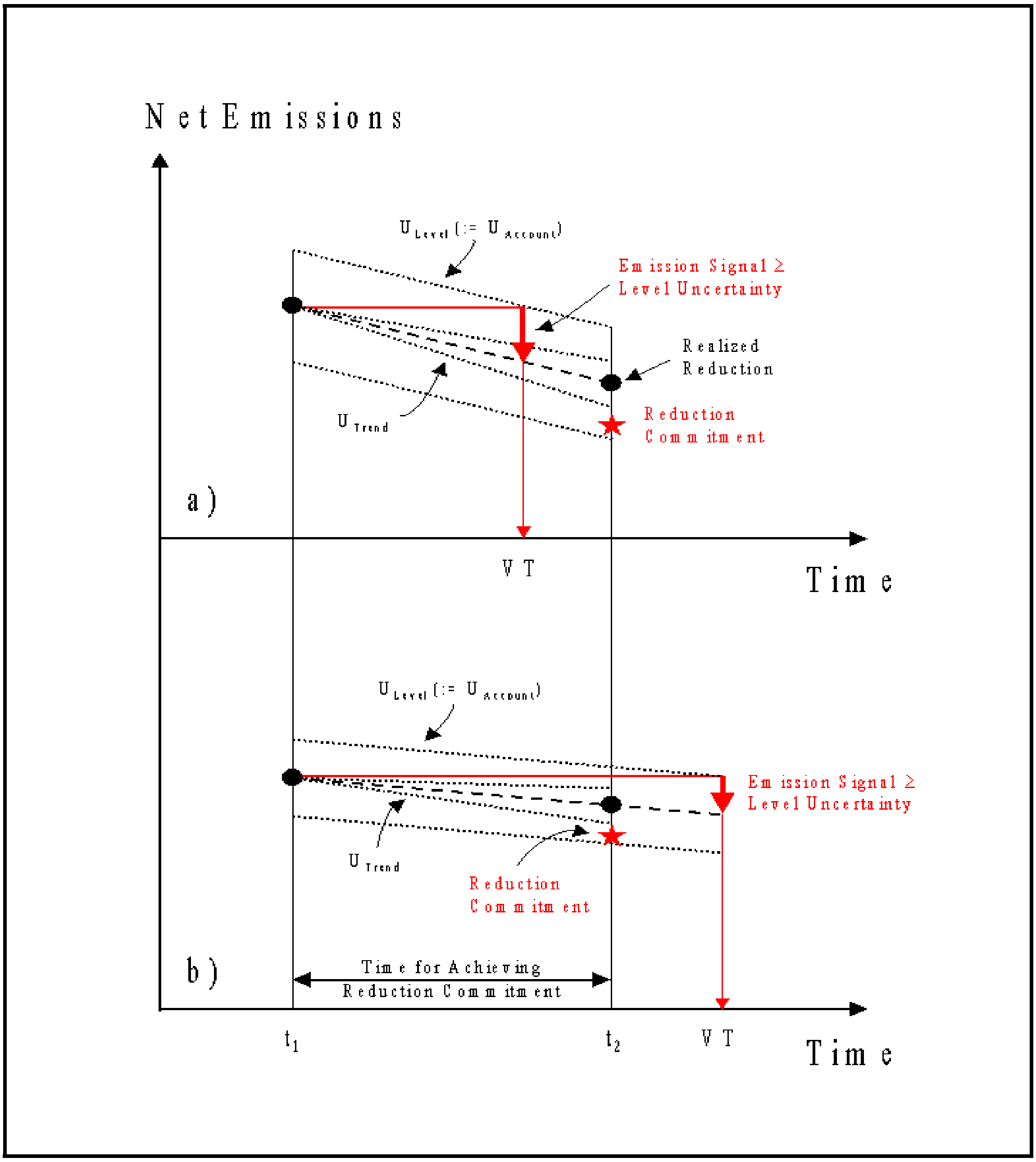

Figure 5: Simplified (linear) graphical representations of the VT concept for a) VT < $t_2 - t_1$ and b) VT > $t_2 - t_1$, indicating that the dynamics of emission signals requires consideration. Here, $U_{Level}(t_2) = U_{Level}(t_1)$.

The VT concept can help to overcome such an accounting deadlock. In Figure 5a the VT is smaller than the time for achieving the reduction commitment (t_2-t_1), confirming (1) that the realized emission reduction is indeed a detectable signal, and (2) that the use of trend uncertainty (Case 1) is legitimate (whether or not its use is sensible is another question). By way of contrast, in Figure 5b the VT is greater than the time for achieving the reduction commitment (t_2-t_1), confirming (1) that the realized emission reduction is not verifiable at all at the time point of commitment (the emission signal has not yet outstripped level uncertainty), and (2) that the interpretation of both Case 1 and Case 2 must be rejected.

This discussion certainly gives rise to the question whether or not current recommendations of how to treat uncertainties — thus, verification — mathematically [here we refer particularly to IPCC (2000a, b)] represent today's best available knowledge? We doubt it. The work of whole generations of, e.g., climate change researchers in the field of signal detection is disregarded. The proposed VT concept, which links the emission signal with its underlying level uncertainty, is in line with this community's understanding of detecting noise affected signals (e.g., IPCC, 1990). Trend uncertainty is favored less because it provides — although also important — only second order (change related) information.

3.1.2.2 Issue 2

> *The VT concept is a temporal verification concept that reflects the inaccessibility of consistent FCA on the spatial scales of countries, the principal reporting unit requested under the Kyoto Protocol.*

Consistent FCA[13] on the spatial scales of countries does not only require the measurement of all fluxes, including those into and out of the atmosphere (as observed on earth), but also an atmospheric storage measurement (as observed in the atmosphere), which would — to reflect the needs of the Kyoto Protocol — permit to discriminate a country's *Kyoto biosphere* from its *non-Kyoto biosphere* (see Figure 6). This type of FCA would permit verification, which is ideal because it works bottom up–top down. However, it is unattainable, even on the global scale (see Footnote 9 and Section 3.1.5.1).

This is the reason why we have to substitute consistent FCA, that is, bottom up–top down verification, by a FCA, which is necessary but not sufficient: It is a FCA, which excludes the atmospheric storage measurement and can only be applied and verified temporally.[14] In essence, this inferior FCA considers only the measurement of fluxes. (Note that the measurement of changes in a biospheric stock represents — from a physical point of view — a not necessarily consistent measurement of the involved net flux.)

This explains why the VT concept makes use of F_{net}.

[13] This type of FCA may also be characterized as two-sided, employing the terminology of Section 2.2.2.
[14] This type of FCA may also be characterized as one-sided, employing the terminology of Section 2.2.2.

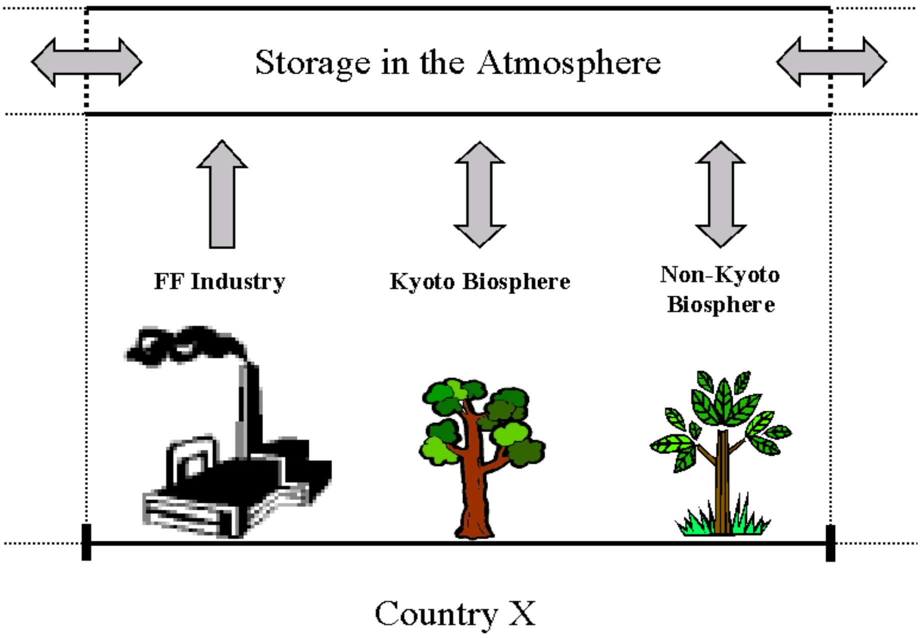

Figure 6: Consistent FCA on the spatial scales of countries requires the measurement of all fluxes, including those into and out of the atmosphere, and an atmospheric storage measurement, which — to reflect the needs of the Kyoto Protocol — would have to permit the discrimination between a country's *Kyoto biosphere* and its *non-Kyoto biosphere*. *FF Industry* also includes ground-based fluxes between countries (e.g., trade) and carbon stocks other than the living biosphere (non-phytomass stocks[15]).

3.1.2.3 Issue 3

As of today, verification priorities of global carbon research differ from those under the Kyoto Protocol.

We raise this issue and deliberately take a discordant view, because we feel that even experts are not fully aware of the physical verification environments, within which the two scientific communities operate.

Briefly, but correctly, it can be stated that global carbon research focuses primarily on the global and sub-global (regional) quantification of carbon sources and sinks and their combination in a closed budget, as well as understanding how the budget changes with time as a function of natural and anthropogenic perturbations. A number of measurements, including those of carbon isotopes and atmospheric oxygen as well as eddy covariance measurements, are combined for ferreting out the different fluxes that

[15] Here, and in the remainder of our Study, we follow common practice and use the terms *phytomass* and *biomass* interchangeably.

result from the use of fossil fuels or are exchanged between land or ocean and atmosphere (e.g., Heimann, 1996; IPCC, 1996: Chapter 2; IGBP, 1997; Heimann *et al.*, 1999; Battle *et al.*, 2000; Falkowski *et al.*, 2000; Pedersen, 2000; Canadell and Noble, 2001). In principle, this community chases the footsteps of bottom up–top down verification on global and sub-global scales.

By way of contrast, the Kyoto Protocol requires that net emissions of specified GHG sources and sinks, including those of the *Kyoto biosphere* but excluding those of the *non-Kyoto biosphere*, be verified on the spatial scale of countries by the time of commitment, relative to the emissions in a specified base year (FCCC, 1998; WBGU, 1998; IPCC, 2000a, b; Jonas *et al.*, 2000; as well as Footnote 31). The relevant question is then whether these changes outstrip uncertainty and can be verified — temporally — which brings us back to the vexing problem of verification under the Kyoto Protocol, already discussed in Section 3.1.2.2.

However, although we see limitations in how the global carbon research community can contribute specifically to the issue of country-scale verification under the Kyoto Protocol, there is not the slightest doubt about the future need of their guiding work on global and sub-global scales and related to other Kyoto relevant issues (see, e.g., Steffen *et al.*, 1998; Schulze *et al.*, 2000; IGBP, 2001).

3.1.2.4 Issue 4

> *The VT concept requires spatio-temporally processed signals, but does not tell us, how to derive them.*

Up to now, we used simplified (linear) representations to illustrate the VT concept graphically (see, e.g., Figure 5). If the signal reveals higher order dynamical moments, we are confronted with the question what the appropriate temporal resolution of the signal is, given the spatial resolution of a country (or a project).

This question is not trivial because it is not clear whether a 5-year commitment period (2008–2012) is sufficient at all to define particularly biospheric signals, that is, to process (smooth) a time series of annual values and derive a change that outstrips uncertainty.[16] It must be expected that a country with a strong biospheric signal in combination with a weak fossil fuel signal will reveal signal characteristics that are different from those of a country with only a fossil fuel signal.

We mention this issue because (1) it prepares the reader for the following example, which corroborates our conjecture, and (2) it represents the starting point for a number of successive signal-related problems.

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[16] Smith (2001) argues similarly in regard to soil carbon. He concludes that most agricultural practices will not cause the soil to accumulate sufficient carbon during a 5-year commitment period. By *sufficient* he means the minimum difference (= 5 tC ha^{-1}) that could be detected with a reasonable sample size and a good statistical power (90% confidence).

3.1.2.5 Example

Global VT calculations as a means to achieve insights into sub-global VT characteristics.

For a number of reasons, viz.:

- data availability,
- availability of a FCA, which is consistent and permits correct PCA, and
- spatio-temporal conditions, which support the application of Equation (4-3) in its present form,

Jonas *et al.* (1999b) constructed four conceptual cases on the global scale and calculated their VTs. A summary of the carbon fluxes for these four cases is presented in Table 2. Cases 1 and 2 are evaluated under FCA, and include a Business-as-Usual Case [BaU] and the BaU case modified by the implementation of a representative LUCF program — in this case, a global afforestation program designed by Nilsson and Schopfhauser (1995) for carbon sequestration [BaU+LUCF].[17] Cases 3 and 4 represent the translation of Cases 1 and 2 to a PCA basis, with Case 3 considering business-as-usual restricted to fossil fuel emissions [BaU(FF)] and the second considering fossil fuel emissions plus the previously mentioned global afforestation program [BaU(FF)+LUCF]. All of these cases are global-scale cases, in which carbon sources and sinks are treated on a global basis.

The key idea underlying these VT calculations is that temporal verification — thus, verification conditions on sub-global scales (see Section 3.1.2.2) — is simulated; the information on global atmospheric carbon storage is not considered for bottom up–top down verification purposes.[18] In practice, this means that the uncertainty that underlies F_{net} is used, not the smaller uncertainty that underlies the atmospheric storage (see last column in Table 2). The drawback of this approach is that the oceanic carbon system had to also be considered, in addition to the anthropogenic fossil fuel system and the terrestrial biosphere. However, this *enlargement of nature* does not pose any difficulties, because it does not influence the VT calculations fundamentally.

The authors use Equation (4-3) to estimate the global VT for each of the four cases. For data availability reasons, they selected the decade of 1980–1989 as the basis for their calculations (t_1 = 1 Jan. 00GMT, 1985).[19] The key to evaluating these cases is to determine the current rate of change in carbon emissions, together with their associated uncertainty. The functional form of Equation (4-3) and the specific values for rates of emission changes and uncertainties for each of these cases is summarized in Table 3. (The reader is referred to IR-99-062 for the details. Here, the focus is on the interpretation and generalization of the results.)

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[17] For convenience, the abbreviation *LUCF* instead of *LULUCF* is used in Section 3.1.2.5.

[18] The atmospheric storage information was only used as a convenient means to estimate the rate of change in net emission $\left(\left| \frac{dF_{net}}{dt} \right|_{t_1} \right)$.

[19] At the time of writing the IIASA Interim Report IR-99-062, the latest global carbon budget (1989–1998) was not available; it only became available by IPCC (2000b). However, the new budget does not influence the VT calculations fundamentally.

Table 2: Cases 1 to 4: Annual average budget of CO_2 perturbations, under FCA and PCA, for 1980–1989. Flows and reservoir changes are expressed in GtC yr^{-1}. Error limits correspond, or were assumed to correspond (only in the case of the global afforestation program), to an estimated 90% confidence interval. Sources: IPCC (1996), Tans and Wallace (1999), Nilsson and Schopfhauser (1995), Schopfhauser (1999).

Case	Fluxes into/out of the Atmosphere (GtC yr^{-1})							Storage in Atmosphere (GtC yr^{-1}) (uncertainty not used)
	In			Out				
	Fossil Fuel Comb. and Cem. Prod.	Tropical Land-use Change	Total	Ocean Uptake	Terr. Ecosystems Uptake	Global Afforest	Total	
FCA: BaU	5.5 ± 0.5	1.6 ± 1.0	7.1 ± 1.1	2.0 ± 0.8	1.8 ± 1.6		3.8 ± 1.8	3.3 ± 0.2
FCA: BaU+LUCF	5.5 ± 0.5	1.6 ± 1.0	7.1 ± 1.1	2.0 ± 0.8	1.8 ± 1.6	0.2 ± 0.1	4.0 ± 1.8	3.1 ± 0.2
PCA: BaU(FF)	5.5 ± 0.5		5.5 ± 0.5					3.3 ± 0.2
PCA: BaU(FF)+LUCF	5.5 ± 0.5		5.5 ± 0.5			0.2 ± 0.1	0.2 ± 0.1	3.1 ± 0.2

Table 3: Cases 1 to 4: Case-specific values for parameters of Equation (4-3), along with resulting estimates of verification time for potential reductions in uncertainty. The rate of change in sequestration is denoted by m_{aff}.

Case (Cf. Figure 7)	Rate of Change of Net Carbon Emissions into the Atmosphere (GtC yr^{-1} / yr) $\left\|\frac{dF_{net}}{dt}\right\|_{t_1}$	Uncertainty (GtC yr^{-1}) $\varepsilon(t_1)$	Verification Time (yr) — If Uncertainty is Reduced Annually by 0%	2.5%	5%
FCA: BaU ■	$\left\|\frac{dF_{BaU}}{dt}\right\| \approx 0.039$	ε_{BaU} ≈ 2.1	**54** $\left(\frac{d\varepsilon}{dt}\right)_{t_1} = 0$	**23** $\left(\frac{d\varepsilon}{dt}\right)_{t_1} = -0.053$	**15** $\left(\frac{d\varepsilon}{dt}\right)_{t_1} = -0.105$
FCA: BaU +LUCF ▲	$\left\|\left(\frac{dF_{BaU}}{dt}\right) - m_{aff}\right\| \approx 0.039 - 0.025 = 0.014$	$\varepsilon_{BaU+LUCF}$ ≈ 2.1	**> 60** $\left(\frac{d\varepsilon}{dt}\right)_{t_1} = 0$	**32** $\left(\frac{d\varepsilon}{dt}\right)_{t_1} = -0.053$	**18** $\left(\frac{d\varepsilon}{dt}\right)_{t_1} = -0.105$
PCA: BaU(FF) ●	$\left\|\frac{dF_{BaU(FF)}}{dt}\right\| \approx 0.146$	$\varepsilon_{BaU(FF)}$ ≈ 0.5	**3.4** $\left(\frac{d\varepsilon}{dt}\right)_{t_1} = 0$	**3.2** $\left(\frac{d\varepsilon}{dt}\right)_{t_1} = -0.013$	**2.9** $\left(\frac{d\varepsilon}{dt}\right)_{t_1} = -0.025$
PCA: BaU(FF)+ LUCF ◆	$\left\|\left(\frac{dF_{BaU(FF)}}{dt}\right) - m_{aff}\right\| \approx 0.146 - 0.025 = 0.121$	$\varepsilon_{BaU(FF)+LUCF}$ ≈ 0.5	**4.1** $\left(\frac{d\varepsilon}{dt}\right)_{t_1} = 0$	**3.7** $\left(\frac{d\varepsilon}{dt}\right)_{t_1} = -0.013$	**3.4** $\left(\frac{d\varepsilon}{dt}\right)_{t_1} = -0.025$

For their analysis, the authors took advantage of the fact that the global carbon budget of the IPCC is balanced (bottom up–top down) to the best of today's available knowledge, and that this balancing eliminates systematic errors. However, this fact is not conditional for their findings. Uncertainties are assumed to be independent. The authors' calculations indicate that this is a reasonable assumption, as it does not fundamentally affect the VTs calculated below.[20] Thus, the overall uncertainty of the total carbon flow into/out of the atmosphere, arising from the combination of the carbon sub-flows into/out of the atmosphere, is calculated (similar to the standard deviation) as the square root of the sum of the squares of the individual uncertainties (e.g., IPCC, 1996; Tans and Wallace, 1999; IPCC, 2000b).

The rate of change of uncertainty is handled by assumption in Equation (4-3). The authors translated specific values of $\left(\frac{d\varepsilon}{dt}\right)$, the rate of change in uncertainty, into percentages. They examined three possibilities for each case — first, that the uncertainty does not change; second, that the uncertainties in carbon emissions are linearly reduced by 2.5% per year (i.e., uncertainty is effectively zero after forty years); and finally, that the uncertainties are reduced by 5% per year (i.e., uncertainty is effectively zero after twenty years).

The appropriate formulation of Equation (4-3) for each of the four cases, along with resulting estimates of VT, are given in Table 3 and displayed graphically in Figure 7. The figure shows the dependence of the VT on the rate of change in uncertainty at time t_1, $(d\varepsilon/dt)_{t1}$. Based on this figure, the authors presented two conclusions, which are of interest here. The first is straightforward. Conveying the general meaning, the authors stated:

1. PCA (small VTs) is much more amenable to favorable verification than FCA (great VTs). This is primarily due to the large rate of change in gross fossil fuel emissions, in comparison with the considerably lower rate of change in the net global carbon emissions under FCA. One can also see that due to this large rate of change in fossil fuel emissions, the effect of including LUCF is much less significant (the two PCA curves are less far apart than the two FCA curves).

   It becomes obvious that it is the signal dynamics in the first instance, which discriminates PCA and FCA systems from each other. The rate of change in uncertainty is (here) only of secondary importance.[21]

[20] It is the uncertainty of the terrestrial ecosystems uptake (± 1.6 GtC yr^{-1}; see second column under *Fluxes out of the Atmosphere* and line *FCA: BaU* in Table 2), which is derived with the help of other uncertainties (in line *FCA: BaU* in Table 2), but which is assumed to be statistically independent here. The following calculation shows that this does not influence the VT calculations fundamentally: Set the uncertainty of the terrestrial ecosystems uptake to zero (situation of perfect knowledge). This reduces the uncertainty of F_{BaU}, ε_{BaU} (see column *Uncertainty* and line *FCA: BaU* in Table 3), from 2.1 to 1.4 GtC yr^{-1}, resulting in a VT of 36 years instead of 54 years in the case of 0% annual reduction of uncertainty. This VT is still about a magnitude greater than those of Cases 3 [PCA: BaU(FF): 3.4 years] and 4 [PCA: BaU(FF)+LUCF: 4.1 years], the two PCA cases restricted to or dominated by fossil fuel emissions. It is this type of first order physical knowledge, which the authors seek.

[21] This corroborates Footnote 11.

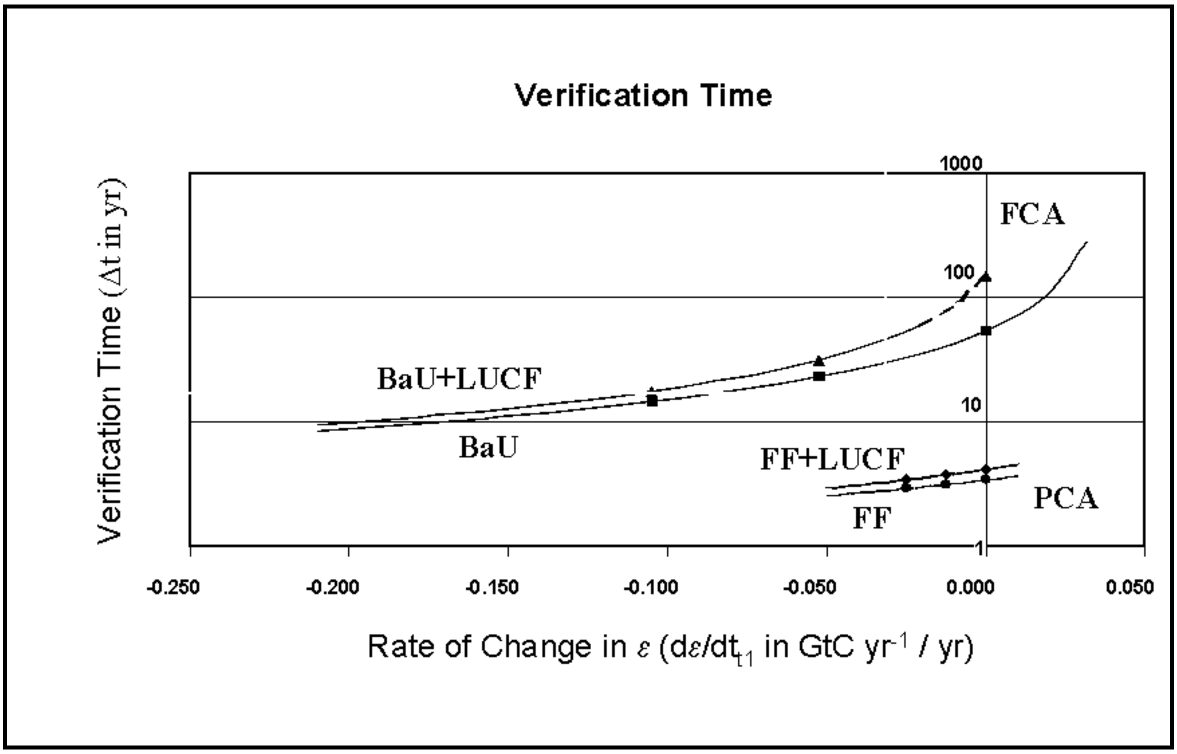

Figure 7: Cases 1 to 4: Time required for verifying projected emission changes as a function of changes in uncertainty in emission rates. The marked points (▲, ■, ◆, ●) on the VT curves are identical with those mentioned in Table 3.

The second conclusion is less straightforward. It builds on the assumption that Kyoto eligible LUCF activities reveal, in general, slower dynamics than national fossil fuel systems. The argumentation is somewhat cumbersome (and will need for its corroboration the ongoing IIASA study mentioned in Footnote 11, which will be able to handle the comparison of dynamical systems in terms of VTs more elegantly). Nevertheless, the argumentation is correct in general and, therefore, also repeated here. Conveying the general meaning, the authors stated:

2. From the above calculations, one might conclude that PCA, restricted to CO_2 emissions from fossil fuel combustion and cement production in combination with a global afforestation program (FF+LUCF case), can be implemented under the Kyoto Protocol. This conclusion, however, is not valid. Implementing Kyoto eligible LUCF activities may result in verification conditions that are unfavorable on the national scale, in contrast to the global-scale results shown above.

   On national scales, parameter combinations resulting from the combination of Kyoto eligible LUCF activities with FF emissions are conceivable that may let the fraction on the right side of Equation (4-3), and therefore the VT, become very great as a consequence of a large amount of uncertainty in the national carbon account and/or a relatively low rate of carbon emission change $\left(\left| \frac{dF_{net}}{dt} \right|_{t_1} \approx 0 \right)$. This is shown, in principle, in Figure 8.

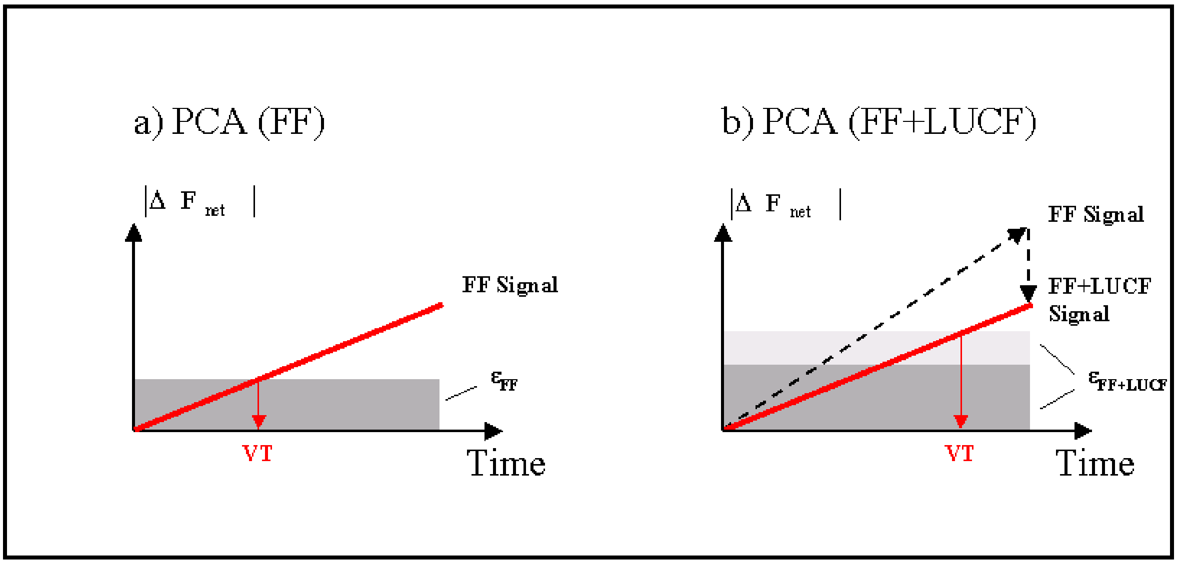

Figure 8: Simplified illustration: a) PCA (FF) and b) PCA (FF+LUCF). The two Kyoto eligible systems reveal identical effective signals, but different uncertainties (ε_{FF} and $\varepsilon_{FF+LUCF}$, respectively, with $\varepsilon_{FF} < \varepsilon_{FF+LUCF}$) and thus different VTs.

Therefore, a major political challenge in using PCA within the framework of the Kyoto Protocol is to demonstrate that no country can position itself under unfavorable verification conditions by implementing Kyoto eligible LUCF activities. By doing so, these countries would gain an advantage over other countries, such as those that manage only FF emissions that can be verified. Countries positioned under unfavorable verification conditions would potentially be able to escape sanctions for non-compliance by claiming that their carbon accounts require more time for verification.

The counter-argument that unfavorable verification conditions may also be possible in the absence of Kyoto eligible LUCF activities (i.e., under the FF case) is not a strong counter-argument. There are three reasons for this, which the authors illustrated by considering the stabilized emissions case:

- Fossil fuel emissions can be reduced, in general, much more rapidly than carbon sequestration can be achieved through LUCF activities. That is, changing $\left|\frac{dF_{FF}}{dt}\right| \approx 0$ to $\frac{dF_{FF}}{dt} < 0$ can be realized more easily than changing $\left|\frac{dF_{FF+LUCF}}{dt}\right| \approx 0$ to $\frac{dF_{FF+LUCF}}{dt} < 0$. This implies that the time required to pass through the case of stable emissions will be much less if only reductions in fossil fuel emission rates are accounted.
- The uncertainty in fossil fuel emissions ($\varepsilon_{BaU(FF)}$), is smaller than the uncertainty in the combination of fossil fuel emissions and LUCF activities ($\varepsilon_{BaU(FF)+LUCF}$). That is, the uncertainty band surrounding $F_{BaU(FF)}$ is not as wide as the uncertainty band surrounding $F_{BaU(FF)+LUCF}$. Therefore, the verification

time of a fossil-fuel-only case is inherently less than that of a fossil fuel case combined with LUCF activities (see also Figure 8).

- If the uncertainty in fossil fuel emissions ($\varepsilon_{BaU(FF)}$) is not yet sufficiently small, it can be made small within a period of time that is compatible with the commitment periods foreseen by the Kyoto Protocol. The authors believe that it is more difficult to reduce the uncertainty associated with LUCF activities ($\varepsilon_{BaU(FF)+LUCF}$). Mathematically, this is expressed as:

$$\left|\frac{d\varepsilon_{BaU(FF)}}{dt}\right| > \left|\frac{d\varepsilon_{BaU(FF)+LUCF}}{dt}\right| .$$

In light of these two conclusions, the authors recommended to use PCA restricted to CO_2 emissions from fossil fuel combustion and cement production [PCA: BaU(FF) case] as the primary Kyoto carbon accounting approach. If LUCF activities are included, they should be kept in a separate carbon account and not used to offset fossil fuel emissions. The authors argued that the present increase in the FF emissions must be stopped and turned around, independently of LUCF measures for carbon sequestration. Offsetting increasing fossil fuel emissions with LUCF activities designed to sequester carbon may lead to carbon accounts, which cannot be verified within the time period foreseen by the Kyoto Protocol (see also Nisson *et al.*, 2001).

In summary, it can be stated that the authors' conclusions still reveal one important drawback, as advocators of (combined FF and) LUCF activities could still argue that claims about long LUCF response times are false, at least in specific cases such as halting deforestation. Indeed, this may very well be so. (To sort out this question, IIASA's ongoing research aiming at directly comparing the verification potentials of dynamical systems is supposed to provide support.) However, the authors' conclusions are built upon averaged FF systems and sets of LUCF activities, not on specific ones.

While an in-depth investigation of this issue has to be left for future research, it will be interesting to see that the authors' argument of keeping LUCF activities in a separate account receives strong support from another study presented below (see Section 3.1.5).

3.1.3 IIASA Interim Report IR-00-021

Full Carbon Account for Russia
By: S. Nilsson, A. Shvidenko, V. Stolbovoi, M. Gluck, M. Jonas and M. Obersteiner

This IIASA Interim Report reveals research that is both deductive as well as inductive. It was the first to present FCA at a national level and the data generated. To create the FCA, IIASA drew on its existing internal database resources and on an extensive network of Russian partners to develop a system of georeferenced descriptions of Russia's land and its component ecosystems. The analyses follow a systems approach, and examine various carbon pools and fluxes in soils, terrestrial biota, agricultural products, and forest products, as well as in animal husbandry and the energy sector. The report includes data on all carbon pools and fluxes in Russia for 1990, and estimates on corresponding data for three alternative scenarios of economic development to 2010.

The IIASA researchers (Nilsson *et al.*, 2000a) argued that such FCA requires not only highly detailed studies of complex natural and anthropogenic processes and their interactions, but also identification and quantification of the associated uncertainties. In addition, the FCA system would have the advantage that it identifies possible biases often ignored under the PCA approach hitherto used to determine carbon sources and sinks (see also IIASA, 2000a, b).

Following this description, the IIASA report can be well considered as a precursor study to the ACDb Study. However, there is an important difference between the two particularly in regard to when and how uncertainty was considered to be a determinative element of the investigations. Contrary to the Russian case study, the ACDb Study paid equal attention to the first (net emissions: F_{net}) and second statistical moments (uncertainty: $U_{Account}$) from the very beginning. This difference was determinative for the course of the ACDb Study, which we will elaborate in more detail in the inductive research phase (Part 4) of our Study.

Here, we are only interested in the main conclusions, which the IIASA researchers drew from their Russian case study (see also IIASA, 2000a, b and Nilsson *et al.*, 2000b, 2001, 2002):

1. "Under current conditions, the targets to which the 39 Annex I countries have committed themselves under the Kyoto Protocol cannot be verified."
2. "Given the wording of the Protocol and the current knowledge base, countries can circumvent their Kyoto targets."
3. "Only FCA that includes uncertainty assessments can lead to the transparent, consistent, comparable, accurate, and verifiable accounting system required by the Kyoto Protocol for deduction of changes in the carbon budget at the national level. Without uncertainty estimates (not considered by the Kyoto Protocol) no verification can occur."
4. "With no reliable verification tool, it is impossible to effectively assess the different activities eligible according to the Kyoto Protocol."

In principle, all four conclusions build upon the huge level uncertainty range for the estimated total flux balance in 1990, which was reported to amount to more than 100%, without taking biases into account. (For comparison, the uncertainty range for Russia's fossil fuel emissions in 1990 was specified by 17%.)[22] The researchers thus argued that any improvement in Russia's total carbon balance falls completely within this assessed uncertainty range; that is, the uncertainties of the accounts dwarf the changes in the total flux balance well beyond the compliance period mandated by the Kyoto Protocol.

In addition, the first conclusion borrows insight from Gusti and Jęda (2002), who introduced the notion of critical relative uncertainty, R_{crit} (see Figure 9). Similar to the VT concept, this uncertainty is based upon level uncertainty, not trend uncertainty. Assuming *perfect compliance* with the Kyoto Protocol and that the relative uncertainty of a country's net emissions are the same in 1990 and 2010, R_{crit} represents the

[22] In general, these uncertainties were assumed to correspond to an estimated 90% confidence interval.

maximum relative uncertainty that still permits favorable verification in 2010. Mathematically, this is expressed as:

$$R_{crit} = \frac{\varepsilon_{2010,max}}{F_{net,2010}} * 100\% = \frac{|1-k|}{k} * 100\% \ , \qquad (4\text{-}5a,b)$$

where

$$k = \frac{F_{net,2010}}{F_{net,1990}} \ . \qquad (4\text{-}6)$$

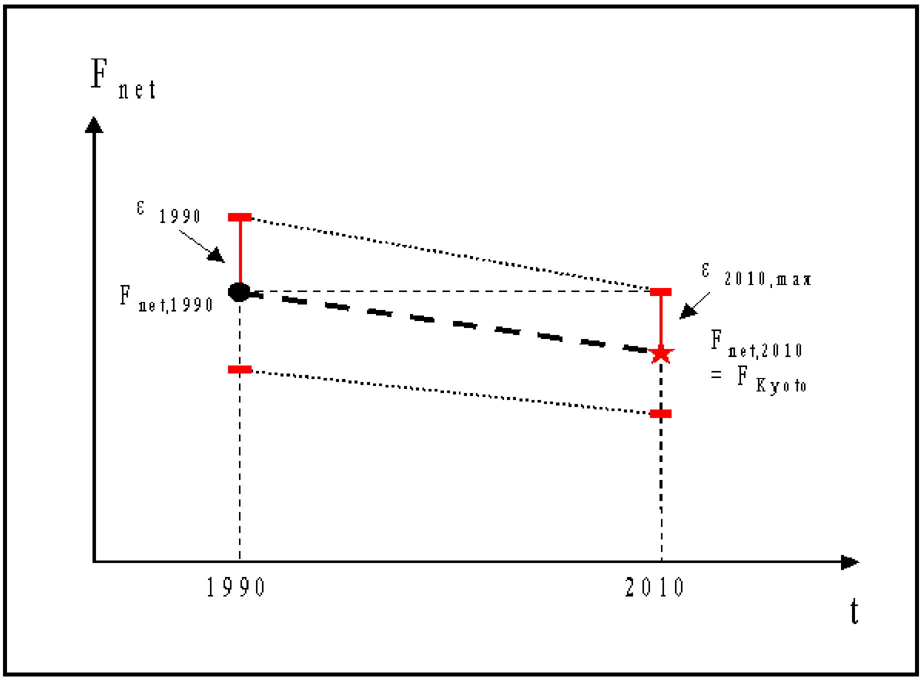

Figure 9: Illustration of the critical uncertainty concept: ε_{1990} and ε_{2010} are the absolute level uncertainties in the base year (1990) and commitment year (2010), respectively; and (ε_{1990} / $F_{net,1990}$) = (ε_{2010} / $F_{net,2010}$). Source: Gusti and Jęda (2002).

Figure 10 displays Equation (4-5b) graphically, along with the positions that groups of Annex I countries hold (see *ISO Country Codes*). For instance, a country of group 1 has committed itself to reduce its net emissions by 8%. In the case of perfect compliance and under the condition (ε_{2010} / $F_{net,2010}$) ≈ (ε_{1990} / $F_{net,1990}$), the country's net emissions in 2010 can only be verified favorably, if they are reported with an uncertainty (e.g., corresponding to a 90% confidence level) that is smaller than 8.7%. Thus, the concept of critical relative uncertainty provides first order guidance on uncertainty and verification, knowledge that one may wish to have at hand before negotiating international environmental treaties such as the Kyoto Protocol. It informs us how great level uncertainties can be depending on the signal we wish to verify, assuming *perfect compliance.*[23]

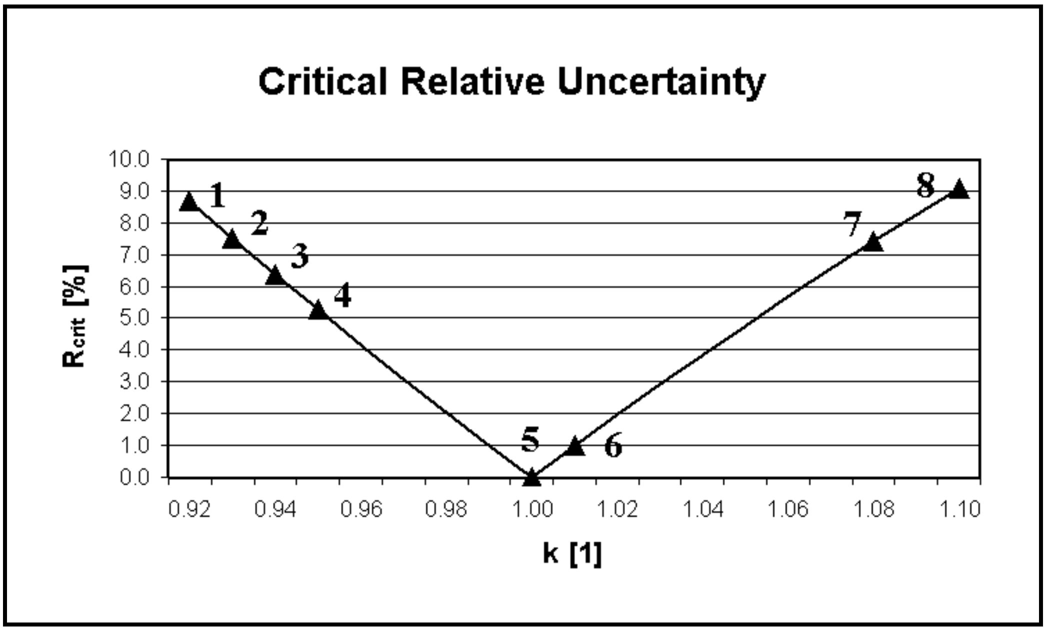

Figure 10: Critical relative uncertainty for Annex I countries: **(1)** AT, BE, BG, CH, CZ, DE, DK, EC, EE, ES, FI, FR, GR, IE, IT, LI, LT, LU, LV, MC, NL, PT, RO, SE, SI, SK, UK; **(2)** US; **(3)** CA, HU, JP, PL; **(4)** HR; **(5)** NZ, RU, UA; **(6)** NO; **(7)** AU; **(8)** IS.

The uncertainties reported in the Russian case study are presently scrutinized as there is new knowledge unfolding, which may justify their reduction (see also Shvidenko and Nilsson, 2001).

3.1.4 IIASA Interim Report IR-00-043

Avoiding a Lemons Market by Including Uncertainty in the Kyoto Protocol: Same Mechanism — Improved Rules
By: M. Obersteiner, Y. Ermoliev, M. Gluck, M. Jonas, S. Nilsson and A. Shvidenko

This IIASA Interim Report deserves mention in this Study. However, physical insights gained in the meantime justify reconsidering some of the arguments and results presented in the report.

The authors (Obersteiner *et al.*, 2000a) of the report are of the opinion that the Kyoto Protocol is in a serious predicament because its economic mechanisms do not consider the issue of uncertainty in the process of mutual recognition of emission reductions between Annex I countries. They argued that a lack of appropriate institutions that police emission reporting would lead to a disintegration of the carbon market due to

[23] Figure 10 also indicates that the stabilized emissions case requires uncertainties that are at least *small*.

competition induced quality deterioration of reporting. Therefore, the introduction of a verification clause in the Protocol's rules would be a first step towards avoiding disintegrative tendencies and carry the potential of improving the Protocol's effectiveness.

In their report, the authors address the problem of considering uncertainty in the Protocol's economic mechanisms. They provided a simplified economic approach that introduces a verification clause into the rules of mutual recognition of emission reductions. The approach is based on the simplified (linear) VT concept discussed above in Section 3.1.2. Otherwise, it follows traditional economic paths, that is, the profit (Π)

$$\Pi = \left(\Delta F - (\varepsilon - \Delta\varepsilon)\right)p - c_F \Delta F - c_\varepsilon \Delta\varepsilon \qquad (4\text{-}7)$$

is maximized by balancing revenues with costs under the condition that:

$$KRT \leq \Delta F - (\varepsilon - \Delta\varepsilon) \qquad (4\text{-}8)$$

(see Figure 11), where p is the competitive market price per ton of carbon and KRT is a country's committed emission reduction target under the Kyoto Protocol. The total revenue is determined by the country's reported emission reduction corrected for its uncertainty at t_2, which is the uncertainty at t_1 (ε) minus the change in uncertainty ($\Delta\varepsilon$) between t_1 and t_2.[24] In combination with Equation (4-8), the following statement holds: The total revenue is > 0, if the emission reduction is verifiable $(\Delta F \geq \varepsilon - \Delta\varepsilon)$ and the Kyoto target has been undershot by the uncertainty at t_2 $(\Delta F - (\varepsilon - \Delta\varepsilon) \geq KRT)$; it is ≤ 0, if the emission target is not verifiable $(\Delta F < \varepsilon - \Delta\varepsilon)$ and/or the Kyoto target has not been undershot by the aforementioned uncertainty $(\Delta F - (\varepsilon - \Delta\varepsilon) < KRT)$.[25]

The authors specify two types of total costs, which arise in the context of reducing either emissions or uncertainty and which the country seeks to minimize:

- The total cost of emission reduction, which is equal to the total amount of carbon reduced over the time period $(t_2 - t_1)$ multiplied by the mean specific cost c_F. This cost depends, among other things, on F or ΔF (but not on ε or $\Delta\varepsilon$), respectively (for details see Obersteiner *et al.*, 2000a.).
- The total cost of uncertainty reduction is equal to the total amount of uncertainty reduced over the time period $(t_2 - t_1)$ multiplied by the mean specific cost c_ε. This cost depends, among other things, on ε or $\Delta\varepsilon$ (but not on F or ΔF), respectively (for details see Obersteiner *et al.*, 2000a).

Maximizing Equation (4-7) in regard to ΔF and $\Delta\varepsilon$ in consideration of Equation (4-8) leads to:

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[24] For simplicity as well as methodological reasons, the authors ignored the application of a discount rate during this period.
[25] In the interval $(\varepsilon - \Delta\varepsilon) < \Delta F < KRT + (\varepsilon - \Delta\varepsilon)$, the price p is set at zero.

$$\Delta F_{opt} = \frac{c_{\varepsilon}^{*}}{c_{\varepsilon}^{*} + c_{F}^{*}} \{KRT + \varepsilon\} + \frac{c_{\varepsilon} - c_{F}}{c_{\varepsilon}^{*} + c_{F}^{*}} \tag{4-9}$$

$$\Delta\varepsilon_{opt} = \frac{c_{F}^{*}}{c_{\varepsilon}^{*} + c_{F}^{*}} \{KRT + \varepsilon\} + \frac{c_{F} - c_{\varepsilon}}{c_{\varepsilon}^{*} + c_{F}^{*}} , \tag{4-10}$$

where

$$c_{F}^{*} := \frac{\partial c_{F}}{\partial \Delta F} , \quad c_{\varepsilon}^{*} := \frac{\partial c_{\varepsilon}}{\partial \Delta\varepsilon} . \tag{4-11a,b}$$

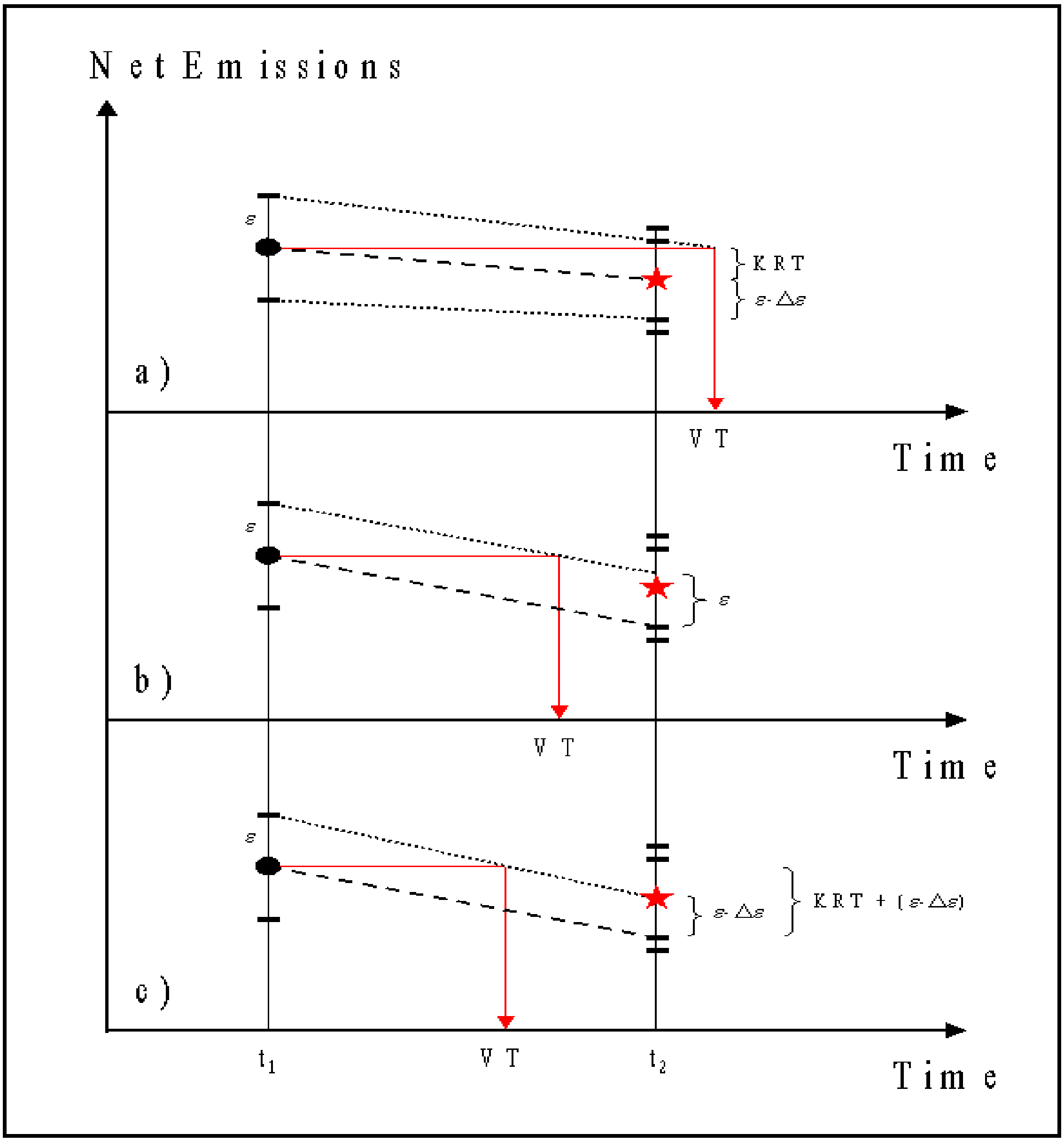

Figure 11: Simplified (linear) three-step illustration featuring the condition of undershooting the Kyoto reduction target (KRT) by the uncertainty (ε-Δε), as requested by Obersteiner *et al.* (2000a).

The emission reduction ΔF_{opt} and the uncertainty reduction $\Delta\varepsilon_{opt}$ are now both optimized in terms of costs and reflect the country's optimal strategy to meet its committed emission reduction target under the Kyoto Protocol, which must — following this economic approach — be undershot by $(\varepsilon - \Delta\varepsilon)$.[26]

The authors substantiate their modeling exercise in more detail in their report. However, the following two fundamental remarks reflect systems analytical insights, which have been gained more recently and, therefore, have not been mentioned by the authors.

3.1.4.1 Remark 1

Environment before economy.

In Footnote 13 and in the *Concluding Remarks* of their report, the authors state that it is interesting to observe that the physical VT concept can be independently derived from an economic approach, i.e., from their revenue function. This statement, of course, requires revision as a linear verification type of thinking in the form of *signal beyond uncertainty* has already been employed in setting up Equation (4-7).

However, of greater importance in the context here is to fully understand what the authors attempted to achieve with the help of their linear modeling exercise. In order to guide the Protocol's economic mechanisms towards success, the authors required that a specific systems condition (here: the VT of a GHG emitting country) is acknowledged and fulfilled before permission is given to the exploration of alternative economic paths, that is, systems constraints are set before the economy is liberalized.

This thought can be generalized, particularly with respect to environmental indicators of biospheric systems that go beyond the concerns of verifying carbon accounts: In order to ensure that environmental objectives (e.g., sustainability criteria) are fulfilled, they must be introduced as a *condicio sine qua non* before economic measures are permitted to take effect.[27] It is this reasoning which underlies the numerous attempts that seek to introduce the notion of sustainability and other environmental standards into the Kyoto Protocol (e.g., Nilsson, 2001; Obersteiner *et al.*, 2001).[28] However, so far, the entire Kyoto policy process has been run in the opposite direction: The economy has been

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[26] Figure 11 indicates that Equation (4-8) is actually too strict and that there is room for fine-tuning, as follows:

$\Delta F < KRT \Rightarrow$ reduction commitment is not fulfilled (this case is not discussed here further);

$\Delta F \geq KRT$: $\Delta F < \varepsilon - \Delta\varepsilon \Rightarrow$ signal is not yet verifiable; undershooting of KRT by $((\varepsilon - \Delta\varepsilon) - KRT)$ is necessary; and

$\Delta F \geq \varepsilon - \Delta\varepsilon \Rightarrow$ signal is or is becoming verifiable; undershooting of KRT is not necessary.

[27] Maximizing Equation (4-7) without considering Equation (4-8) or an equivalent set of conditions, e.g., $\Delta F + (\varepsilon - \Delta\varepsilon) \geq KRT$ (the KRT must be reached) and $\Delta F \geq \varepsilon - \Delta\varepsilon$ (verifiability must be guaranteed) (see also Footnote 26), does not necessarily imply that environmental objectives are fulfilled.

[28] This consideration is also relevant to another Austrian study titled *Rohstoff Landschaft* (Raw Material Landscape), which is conducted by the Austrian Institute for Applied Ecology. Among other things, the investigators attempt to develop recommendations for decision-makers that optimally balance the ecological functioning of forests (CO_2 sequestration) and their economic functioning (forest management) (Egger-Rollig, 2001; FMESC, 2001).

liberalized while the understanding of what the environmental conditions should be has not been specified.

3.1.4.2 Remark 2

The Economists' Achilles heel: Nonlinear systems.

In *The Importance of Verifiability* section of their report, the authors state:

> "Bearing in mind that there are budget constraints for Kyoto measures, we must increasingly acknowledge the importance of the effectiveness of Kyoto measures. Effectiveness could be hampered, in a least cost sense of total net emission reduction, if the full range of carbon reduction measures and the range of GHG is restricted. There is a danger for the post-Kyoto process that certain measures are *a priori* disqualified on the grounds of the large uncertainty they carry… In this paper, …, we argue that uncertainty can be priced and in this way be included in a trading scheme. Within such a trade mechanism of verifiable carbon accounts, biospheric measures could turn out to be cost effective despite large uncertainties in the biosphere."

However, the authors admit (see *Concluding Remarks* in their report) that the general problem of different systems dynamics between biospheric and anthropogenic systems remains, which they propose to overcome by the formation of common markets (see Obersteiner *et al.*, 2000b).

This statement requires revision. In examining Equation (4-7), we realize that the cost functions $c_F = c_F(\Delta F)$ and $c_\varepsilon = c_\varepsilon(\Delta\varepsilon)$ do not reveal inter-dependencies and thus do not support the derivation of cross-derivatives (that is, $\frac{\partial c_F}{\partial \Delta\varepsilon}$ and $\frac{\partial c_\varepsilon}{\partial \Delta F}$). The corresponding physical thinking that underlies this approach is restricted to systems that reveal a linear dynamical behavior, ideally over long time periods, as illustrated principally in Figure 8.

However, the physical reality is more complex as Annex I countries typically reveal a dynamical PCA (FF: CO_2) behavior that is nonlinear (i.e., of higher order) in relation to short time scales, as illustrated principally in Figure 12 (see also Gusti and Jęda, 2002). The consequences can be vexing: The systems' properties, in our case the VT, behave nonlinear as well (in fact, the VT begins to *jump*). Superimposing such a system with a system that reveals a slow (linear or nonlinear) dynamical behavior and/or great uncertainties makes things worse. Instead of mastering nonlinear PCA (FF: CO_2) systems by minimizing their non-verifiable time periods, we do the opposite and increase these periods by combining systems with different dynamics and/or uncertainties, e.g., PCA (FF: CO_2) and PCA (LULUCF) systems, or even PCA (FF: CO_2) and PCA (FF: non-CO_2) systems.

By this it becomes clear that economists cannot go on assuming that their linear theoretical equipment is sufficient in dealing with such short-term nonlinear dynamical problems (see also Rotmans and van Asselt, 2001). In the case of Equation (4-7), a physically more adequate treatment would require cost functions that are inter-dependent and are also treated accordingly, and — in accordance with our previous remark — a condition that ensures verifiability ($VT \le t_2 - t_1$) and the preservation of environmental standards.

Therefore, in contrast to the authors' aforementioned reasoning, our new insights (more correctly: knowledge gaps) suggest that the maxim for our actions under the Kyoto Protocol must rather be to separate systems from one another and tackle them individually, and not intermingle them. We must be aware that — even if we follow this maxim — we are still left with pretentious, highly complex problems that require systems analytical, environmental and possibly other considerations, prior to their economic treatment.

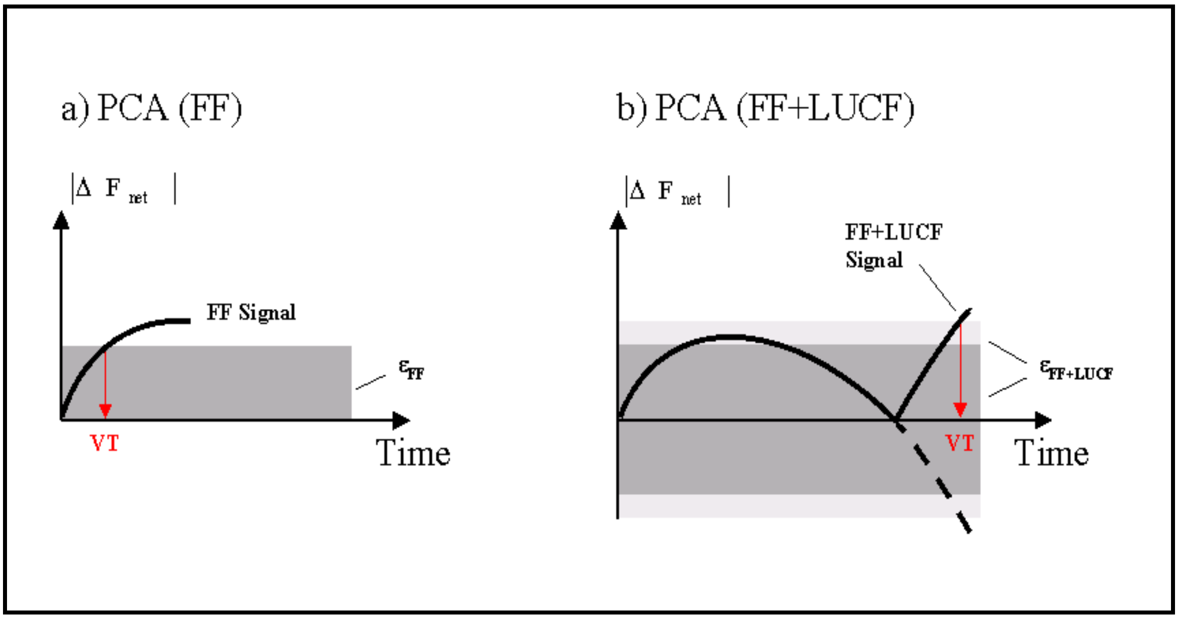

Figure 12: Illustration of the nonlinear behavior of VT: a) PCA (FF) and b) PCA (FF+LUCF). Here, the FF+LUCF signal results from compensating the nonlinear FF signal by a LUCF signal revealing slow dynamics. (The LUCF signal is not shown here for a better overview.)[29]

3.1.5 IIASA Interim Report IR-00-061

How to Go From Today's Kyoto Protocol to a Post-Kyoto Future that Adheres to the Principles of Full Carbon Accounting and Global-scale Verification? A Discussion Based on Greenhouse Gas Accounting, Uncertainty and Verification

By: M. Jonas, M. Obersteiner and S. Nilsson

In this IIASA Interim Report, the authors (Jonas *et al.*, 2000) asked four key questions:

> "Where do we want to go?" "What do we know?" versus "What do we not know?" "Which difficulties do decision-makers face in deciding how to get to there?"

[29] For convenience, the abbreviation *LUCF* instead of *LULUCF* is used in Figure 12.

In answering these questions, the authors attempted to balance insights into fundamentals and principles across disciplines by way of discussion, which was driven by physical and economic arguments. The authors addressed the aforementioned questions by focusing on three issues: GHG accounting (in their report restricted to carbon accounting), uncertainty, and verification.

Of greater importance in the context here are two other questions, which the authors addressed in the *Appendix* of their report: (1) where does carbon accounting currently stand? and (2) what are the scientific requirements stipulated by the Kyoto goal? Below we summarize the authors' answers to these questions. They will constitute a further building stone in understanding the scientific constraint, which obliges us to replace bottom up–top down verification by temporal verification, and thus in drawing the conclusions that will emerge from Part 3.

It is also in the context of the second question, where we follow the authors in making the spatial step from *national* to *sub-national*, that is, to the spatial scales of Kyoto eligible LULUCF activities. So far, our thinking in Part 3 was associated — although not repeatedly mentioned — with the spatial scales of countries, the principal reporting unit requested under the Kyoto Protocol.

3.1.5.1 Question 1

Where does carbon accounting currently stand?

The authors distinguish between accounting carbon (1) on the global scale, (2) on the national scale, and (3) temporally:

1. Global-scale carbon accounting:
   - "Atmospheric carbon measurements allow for FCA and they are global."
   - "Atmospheric measurements offer the potential to distinguish between fossil fuel, terrestrial biospheric and oceanic CO_2 sources and sinks, but not between a *Kyoto biosphere* and a *non-Kyoto biosphere*."

Whether or not it will be possible in the future to distinguish between a *Kyoto biosphere* and a *non-Kyoto biosphere* is another question. However, it can be safely stated that this will not happen in the immediate future (e.g., MPI, 1999; IPCC, 2000a).

2. National-scale carbon accounting:
   - "The Kyoto Protocol envisages PCA [PGA (FF+LULUCF)] on the national scale…"

3. Temporally:
   - "The concept of *comparing mean values on the basis of percentages* is proposed for the anthropogenic CO_2 equivalent emissions… [FF emissions] of Annex I countries."
   - "The concept of subtracting mean values is proposed for land-use change and forestry activities (net LULUCF emissions)."
   - "Changes in net LULUCF emissions are added to the Countries'… [FF] emissions."
   - "Verification of the Kyoto Protocol is considered to be [merely] a technical problem."

As illustrated in Section 3.1.5.2, this method of accounting carbon spatially and temporally reveals severe shortcomings. It does not comply with the scientific requirements stipulated by the Kyoto Protocol and its intended overall objective, which calls for the stabilization of GHG concentrations at a *safe* level (FCCC, 1992; 1998). According to the authors, this implies that net emission reductions must be detectable, i.e., measurable and verifiable, in the atmosphere, arguing that what matters is what the atmosphere sees.

3.1.5.2 Question 2

What are the scientific requirements stipulated by the Kyoto Protocol?

The authors distinguish between (1) spatial requirements, (2) temporal requirements, and (3) the combination of these two:

1. Spatial requirements:
    - "FCA is conditional for all carbon accounting."
    - "FCA on smaller spatial scales does not imply correct carbon accounting on larger spatial scales."
    - "A Kyoto Protocol that can be cross-checked must include [carbon related] data from all nations."

It is here where the authors now make the step from bottom up–top down verification to temporal verification, realizing that a globally embedded bottom up–top down verification that also discriminates a *Kyoto biosphere* from a *non-Kyoto biosphere*, cannot be attained within the immediate future. Graphically, the consequence is that Figure 13 replaces Figure 6.

2. Temporal requirements:
    - "Uncertainty and verification are, first and foremost, fundamental scientific issues."
    - "Both uncertainty and verification must be considered under the Kyoto Protocol. Any accounting without assessing uncertainty does not allow for understanding verification."
    - "We are not yet sufficiently knowledgeable to prioritize among the various uncertainty-verification concepts."
    - "The use of trend uncertainty and level uncertainty may lead to interpretational difficulties."
    - "A physical-based verification concept that has been generalized to grasp uncertainty and verification dynamically over time is believed to provide a more adequate basis for dealing with the uncertainty–verification issue. However, we are only at the beginning of understanding this concept."

As it becomes apparent, the first two of these requirements are not true temporal requirements. However, they are mentioned here, because they reflect the authors' endeavors in addressing the issue of temporal verification (what we did in Section 3.1.2).

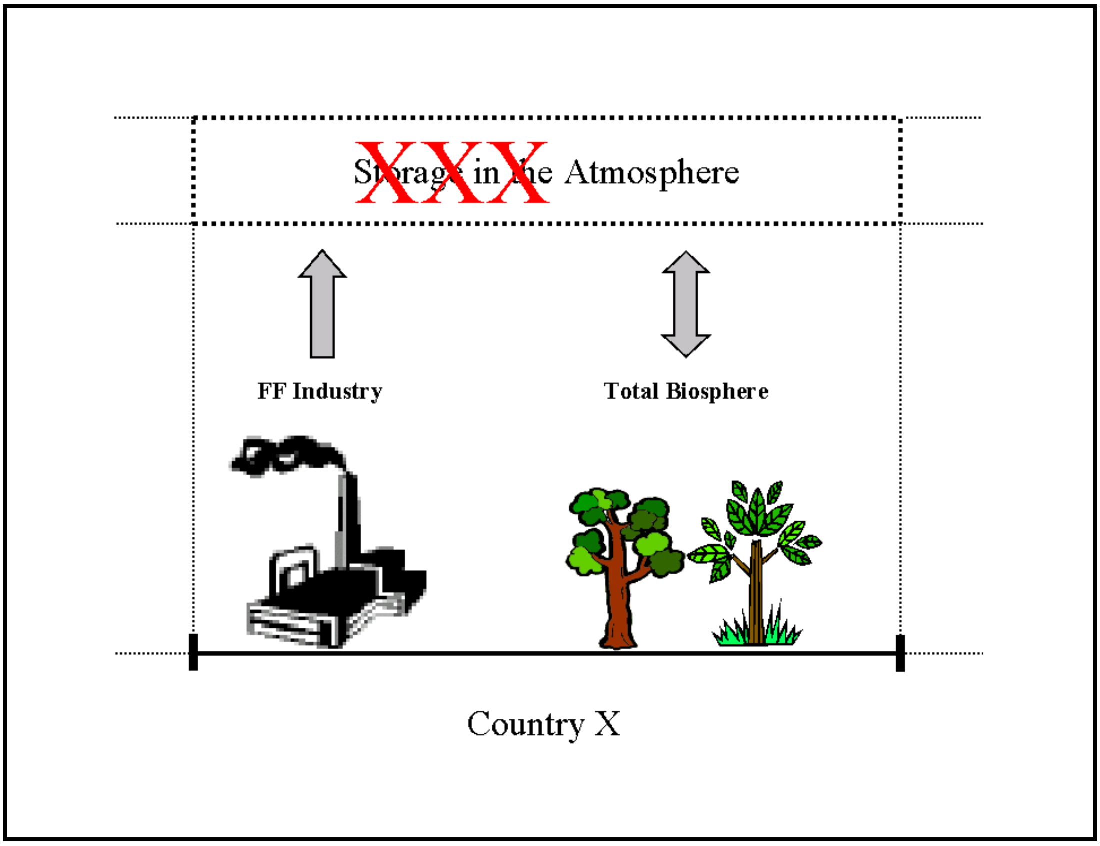

Figure 13: Making the step from bottom up–top down verification to temporal verification: This figure replaces Figure 6 as atmospheric net flux (or storage) measurements on sub-global scales are not, or are unlikely to become, available (indicated by XXX) under the conditions induced by the Kyoto Protocol (see text).

We also note that the two-points-in-time IPCC uncertainty concept has slipped here into the *temporal requirements* category, which we permit by interpreting this concept dynamically in terms of zero-order. However, by now, we are less indefinite with regard to prioritizing among the various temporal verification concepts (see third temporal requirement). The VT concept receives IIASA's primary scientific attention in an ongoing study, which aims at quantifying the verification regimes under which the Annex I countries operate.

In the following step, the authors identify further — spatio-temporal — requirements. They argue that they can do this, irrespective of which temporal verification concept is considered in dealing with the uncertainty–verification issue, by putting temporal verification into the context of FCA, including FCA across spatial scales.

3. Spatial and temporal requirements:
   - "Whether or not FCA implies verifiability depends on the… [temporal] verification concept selected."
   - "… [Verifiable FCA] on smaller spatial scales does not imply… [verifiable carbon accounting] on larger spatial scales."

- "Global-scale verification (bottom up versus top down) is superior to temporal verification on sub-global scales."

As it becomes clear, the authors presuppose FCA — as a consequence of the aforementioned spatial requirements. In this context, the following three reflections need to be added:

(i) Following up on our insights in Section 3.1.2.1, that is, considering that the application of the two-points-in-time IPCC uncertainty concept only leads to necessary, but not sufficient verification, we can now formulate the first requirement more strictly:

- Whether or not FCA implies verifiability depends on whether or not the associated signal is verifiable.

(ii) Global-scale bottom up–top down verification is necessary and sufficient to detect biases, temporal verification on sub-global scales is not (that is, only necessary).

(iii) In addition to bottom up–top down verification on the global scale and temporal verification on sub-global scales, the option also exists of verifying bottom up net emission estimates by top down atmospheric net flux (or storage) measurements on sub-global scales, which may overlap each other spatially (e.g., Jonas *et al.*, 1999a; Nabuurs *et al.*, 1999; Post *et al.*, 2001; Smith, 2001). However, as mentioned by the authors, the availability of this option reveals severe fundamental as well as practical limitations: (1) Discerning a signal of change from the noise of uncertain gross fluxes can take decades. Gross fluxes are large and notoriously uncertain and variable (e.g., Nilsson *et al.*, 2001). (2) It is almost impossible to trace net emissions identified on *larger* spatial scales back to individual sources/sinks or source/sink categories (here: *Kyoto* and *non-Kyoto LULUCF sources/sinks*) if their net emissions do not contain some sort of *fingerprint* that characterizes them (see also IPCC, 2000a). (3) The amount of Kyoto eligible LULUCF activities must be expected to be considerable. This alone poses severe practical constraints on the use of such bottom up–top down cross-checks on *smaller* sub-global scales, which cannot be commonly performed (Jonas *et al.*, 2000; see also Martin *et al.*, 2001; Smith, 2001).

To summarize Section 3.1.5, we list the main shortcomings of the Kyoto Protocol, namely,

- no FCA,
- no top down verification, in particular, as a consequence of splitting the biosphere into a *Kyoto* and a *non-Kyoto biosphere*,
- no rigorous temporal verification,

as they were perceived by the authors at the time of writing their report. They are displayed graphically in Figure 14.

To demonstrate the severeness of these shortcomings, the authors argued that the following extreme, nevertheless relevant, gedankenexperiment can serve as an illuminating example: Assume that all countries comply with a Kyoto Protocol, which focuses on the reduction of FF emissions, but which excludes biospheric sinks and sources. Even under such conditions, bottom up–top down verification of the FF system does not imply global-scale verification of the entire (FF + biospheric) system. This is because emissions from the entire system to the atmosphere may increase, although emissions from the FF system are limited (or reduced). Conditions prevailing in the FF system may trigger adverse activities or processes within the terrestrial biosphere (e.g., increased use of fuel wood, followed by vast deterioration of ecosystems) that counteract and even compensate the emissions from the FF system. According to the authors, this example is relevant because it demonstrates that the way in which the Kyoto Protocol is made operational and eventually ratified may easily run counter to its original intent. They concluded that mankind does not have a scientific tool at hand that helps it to avoid such uncontrollable situations.

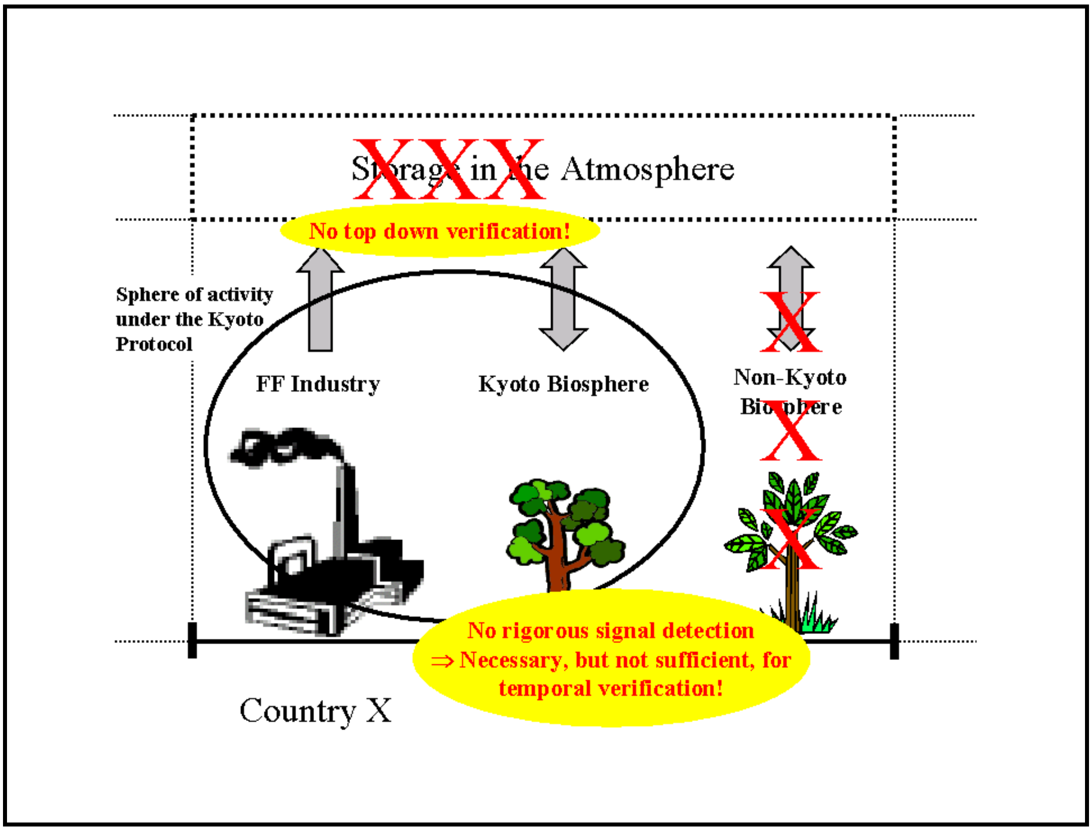

Figure 14: The main shortcomings of the Kyoto Protocol as perceived by the authors at the time of writing their report: (1) no FCA, (2) no top down verification, and (3) no rigorous temporal verification. (XXX indicates the unavailability of atmospheric net flux or storage measurements, as in Figure 13, as well as the exclusion of part of the biosphere under the Kyoto Protocol.)

3.2 Results

With the help of a number of studies, Section 3.1 addresses four central issues from different perspectives. These are FCA, verification, systems revealing different dynamics and uncertainties, and Kyoto eligible mechanisms. The definition of verification used as a reference is taken from the IPCC (2000a: Annex 3). It is sufficient as it specifies verification towards the intended purpose of the Kyoto Protocol, which can only be done from an atmospheric point of view: *What matters is what the atmosphere sees!* This is visualized graphically in Figure 15 and cannot be overemphasized as the understanding of verification varies widely (e.g., Loreti *et al.*, 2001).

This section summarizes the results of the aforementioned studies that were drawn at the time of writing. Section 3.3 outlines the conclusions in consideration of these results, but taking the most recent Kyoto policy decisions into account.

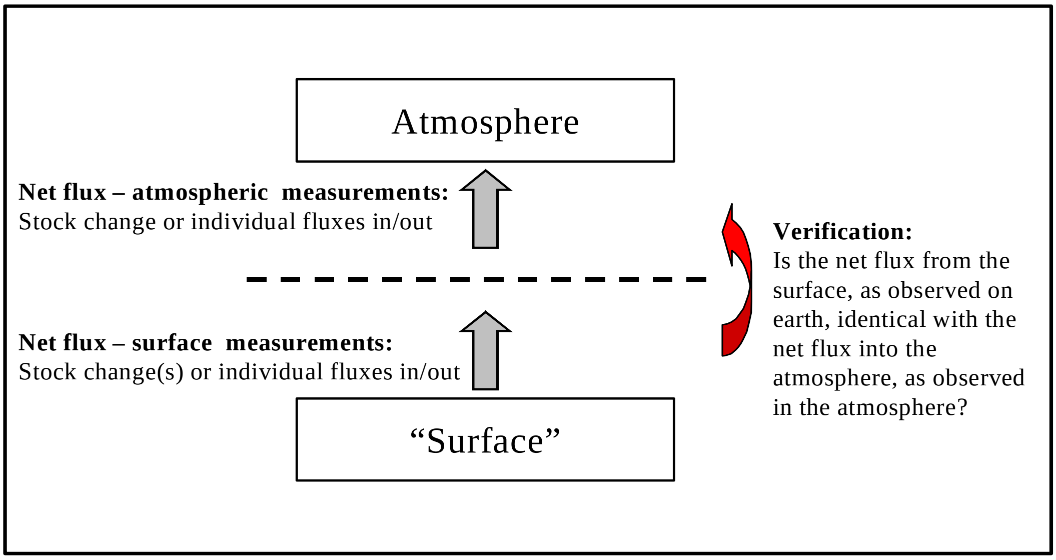

Figure 15: The principle of verification, in accordance with the intended purpose of the Kyoto Protocol. For simplification, fluxes other than the net flux between the earth's surface and the atmosphere are omitted.

The main results of Part 3 (Deductive Research) are largely identical with those of IIASA's Russian case study (see Section 3.1.3), which is not surprising because the studies influenced each other, but its results also go further. They can be summarized as follows:

<u>Related to FCA and verification:</u>

3.1.2.2 3.1.5.1, 3.1.5.2	The Kyoto Protocol supports PCA (FF+LULUCF) in the context of PGA, but not consistent (*two-sided*) FCA.
2.2.2 3.1.5.2	The option of verifying bottom up net emission estimates by top down atmospheric net flux (or storage) measurements on sub-global scales reveals fundamental as well as practical limitations, which severely restricts its application under the Kyoto Protocol.

As a consequence, rigorous bottom up–top down verification (on any spatial scale) is unattainable.

3.1.2.2 3.1.5.1, 3.1.5.2	The Kyoto Protocol also does not aim at *one-sided* FCA (as observed on earth), which could be applied and verified temporally on sub-global scales.
2.2.2 3.1.2.1 3.1.5.2	The IPCC advocates a two-points-in-time uncertainty concept, which grasps uncertainty in regard to two pre-defined points in time. The physical quantity time (how the emission signal evolves between the two identified time points) is disregarded. Treating uncertainties — thus, verification — mathematically in this way does not represent today's best available knowledge. Research in the field of signal detection is disregarded.

The consequence is that the IPCC concept is only necessary, but not sufficient, for temporal verification.

Thus, rigorous verification under the Kyoto Protocol is unattainable. This finding is in conflict with the Kyoto Protocol, which requests verification, and has far-reaching consequences for the Protocol with regard to accounting modalities, compliance, economic mechanisms, etc., as far as the establishment of an appropriate institutional framework.

<u>Related to systems revealing different dynamics and uncertainties:</u>

(This issue is mentioned although it is implicitly included in the aforementioned set of results.)

3.1.2.5 3.1.4.2 3.1.5.1, 3.1.5.2	The Kyoto Protocol splits the biosphere into a *Kyoto* and a *non-Kyoto biosphere* and combines systems with widely differing dynamics and/or uncertainties.

By implementing Kyoto eligible LUCF activities, countries may position themselves under unfavorable verification conditions — provided that temporal verification is measured (that is, a verification concept is introduced, which is sufficient in terms of temporal verification and that replaces the insufficient two-points-in-time IPCC uncertainty concept). By doing so, these countries may gain an advantage over other countries, such as those that manage only FF emissions, which can be verified. Countries positioned under unfavorable verification conditions would potentially be able to escape sanctions for non-compliance by claiming that their carbon accounts require more time for verification.

Even if the maxim of separating systems from one another and tackling them individually is followed, experts are still left with pretentious, highly complex problems that require systems analytical, environmental and possibly other considerations, prior to their economic treatment (see also below).

<u>Related to Kyoto eligible mechanisms:</u>

3.1.4.1	So far, the economy has been liberalized during the Kyoto policy process, while the understanding of what the environmental criteria should be has not been specified.

3.1.4.2 The economists' linear theoretical equipment is insufficient in dealing with short-term nonlinear dynamical and environmentally constrained problems such as Kyoto.

If environmental objectives (e.g., sustainability criteria) are not introduced as a *condicio sine qua non* before economic measures are permitted to take effect, the fulfillment of the objectives under the Kyoto Protocol cannot be ensured.

3.3 Conclusions

This section reaches conclusions in consideration of the aforementioned results and, in doing so, it takes some of the most recent Kyoto policy decisions into account. Of specific interest in the context here are the following outcomes of the Sixth (COP 6/II) and Seventh (COP 7) Sessions of the COP to the UN FCCC (FCCC 2001a, b, c, f; IISD, 2001a, b; Pew, 2001):

- LULUCF has been extended beyond Article 3.3 activities (afforestation, reforestation, and deforestation) by activities that fall under Article 3.4. These are forest management and agricultural activities (cropland management, grazing land management, and revegetation) (see also Appendix 2).

  It may be argued that this is a step towards FCA. However, a number of crucial questions arise that require further consideration (Weiss, 2001). For instance, how *full* is the carbon accounting brought about by Article 3.3 and 3.4 activities, which are defined on the basis of a change in land use? The current understanding among Kyoto policy experts seems to be that the entire managed forest must be considered if a country chooses to take forest management into account, while a similar understanding of completeness has not yet been developed in the case of agricultural activities. Yet another unsettled question is what *full* means in the context of accounting soils (depth, processes, etc.)?[30]

- A compliance regime can set consequences for failing to meet an emissions target but defers until a later Conference the question of whether the consequences are legally binding.

  Here the crucial question arises as to how noncompliance can entail legal consequences if rigorous verification under the Kyoto Protocol is unattainable?[31]

- On the issue of mechanisms' eligibility, an expedited procedure to review the reinstatement of eligibility to use mechanisms was agreed following minor amendments, although time was lacking to appropriately consider this issue.

  The question that has been left unsettled in the context of LULUCF activities is how the mechanisms' expedited liberalization can ensure that LULUCF activities can fulfill environmental objectives (e.g., with respect to conservation of

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[30] We recall that unmanaged forests are excluded from the outset. Their areas may be considerable. In the case of Russia, e.g., their area is at least 40% (Shvidenko, 2001).

[31] We recapitulate that verification is specified as *verification of the inventory data at the national level*, and that uncertainty is supposed to be quantified by using the two-points-in-time IPCC uncertainty concept (see FCCC, 2001c).

biodiversity and sustainable use of natural resources), which have not yet been specified?

It becomes apparent that matters have not improved and that the Kyoto Protocol urgently needs fundamental improvements, more than ever before. In order to guide the Protocol towards success, we conclude in consideration of the above (see also Section 3.2):

- A robust FCA system (embedded into a proper FGA system), which permits the quantification of uncertainties within this wider context, is required. Only such an accounting system can form a solid basis for accounting GHG emissions and removals under the Kyoto Protocol.
- The biosphere must be treated as one system and must not be split into a *Kyoto* and a *non-Kyoto biosphere*.
- The two-points-in-time IPCC uncertainty concept must be replaced by a verification concept that is sufficient in terms of temporal verification.
- Bifurcated rules (actually, Protocols) are needed that treat the more easily verified fluxes (FF CO_2, especially) differently from those that are more uncertain (notably, LULUCF CO_2).
- An understanding of what the environmental criteria under the Kyoto Protocol should be has to be developed. Environmental objectives (e.g., sustainability criteria) need to be introduced as a *condicio sine qua non* before economic measures are permitted to take effect.

PART 4: Inductive Research

Part 4 takes the reader through our inductive research phase, which covers Objectives 1 (ACBM II Support) and 3 (Good Practice Guidance) of the ACDb Study. It refers to our general experiences (Section 4.1), summarizing our specific experiences from setting up the ACDb modules as well as our results (Section 4.2) and drawing conclusions (Section 4.3). The outstanding research challenges are identified in Section 5.2, together with those from Part 3.

Similar to Part 3, additional studies exist that IIASA has carried out (mainly, but not exclusively) for the support of our research under Part 4. These are the studies by Geisler and Jonas (2001) and Kubeczko (2001a). The first was instrumental in dealing particularly with the uncertainties underlying the carbon flows of the ACDb's FOREST module, while the second is responsible for the realization of the ACDb's PROD and CONSU/WASTE modules. However, in contrast to Part 3, these studies are not presented and summarized individually, but are integrated together with the work of other researchers into the modular structure of the ACDb.

4.1 General Experiences

The purpose of this section is to share important general experiences from setting up the ACDb. These refer to three issues: the incomplete basis of the ACDb, the consequence of including uncertainty in the FCA, and the usefulness of the ACDb. As mentioned in Section 2.1.4 (see also Section 3.3), countries typically operate within a PGA (FF+LULUCF) context that will increasingly encompass the assessment of uncertainties ($U_{Account}$). However, so far, only two national-scale studies exist, IIASA's Russian study and the ACDb Study, that apply a FCA approach and look into $U_{Account}$; and only two national-scale studies, the ACDb Study and the ACBM II study, permitting the investigation of $U_{Account}$ and U_{Model} in parallel, in consideration of FCA. Thus, current knowledge that is available to assist us and guide our research is scarce.

In light of the experiences mentioned below, we also recall one of the three principal conditions that the ACDb Study was requested to fulfill, namely, that it is carried out in close collaboration with and provides comprehensive data support to the ACBM II teams (see Section 2.1.6). As we will see, this condition will give rise to a fundamental discussion on the level of detail, up to which first (net emissions: F_{net}) and second statistical moments (uncertainty: $U_{Account}$) can and should be assembled in the ACDb Study.

4.1.1 Issue 1

The incomplete basis of the ACDb.

When initializing the ACDb Study (as well as the ACBM II study), the researchers were still focussed on the commonly applied method of carbon accounting (and modeling). By this we mean that the basis of their thinking was a *carbon flow framework* in order to realize a FCA approach for Austria (as displayed graphically in Figure 16), not a *material flow framework*. Working within the first means to tackle, in particular, the problem of consistency on the level of carbon flow accounting. By way of contrast, working within the second means to tackle this problem on a precursor level, the level of material flow accounting.

While Geisler and Jonas (2001) perceived the importance of a *material flow framework* over a *carbon accounting framework* particularly in the context of their work on the FOREST module, Kubeczko (2001a) already elaborated a concept of how to realize the general step from material to carbon flow accounting in the future, based on his work on two of the ACDb modules, PROD and CONSU/WASTE.

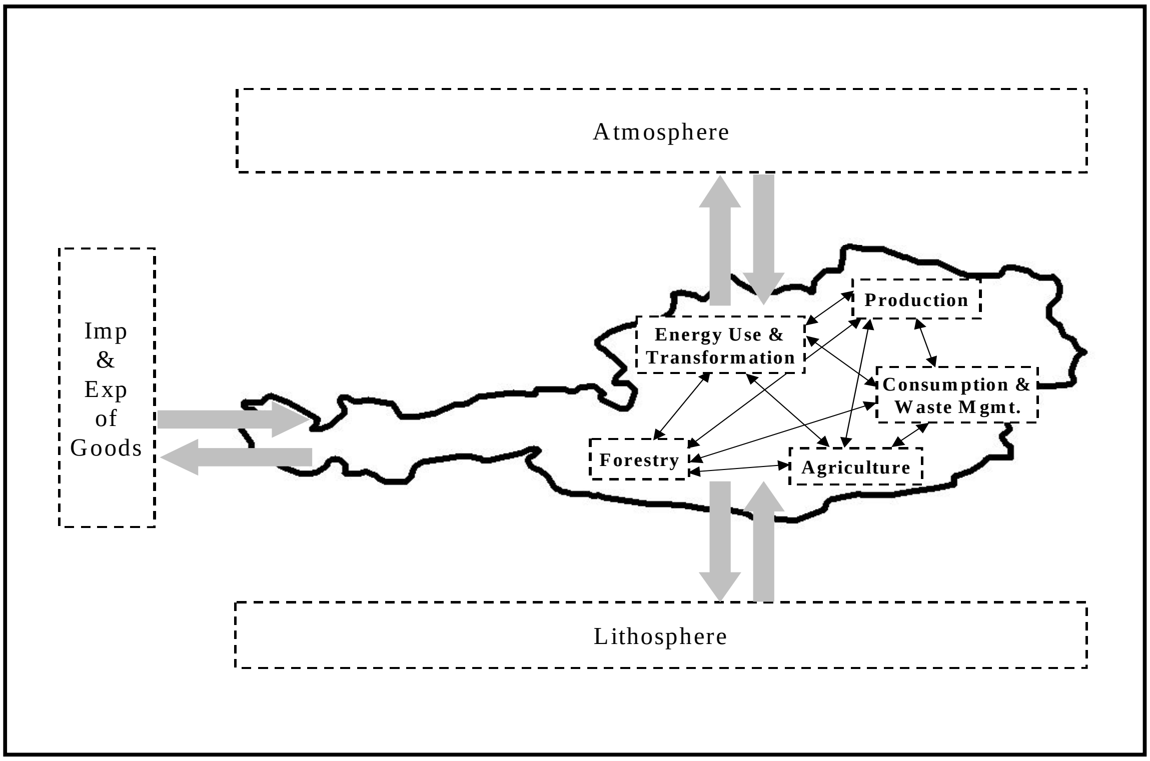

Figure 16: The principal systems concept underlying the ACDb as well as the ACBM II (see also text and Figure 17). Source: Orthofer *et al.* (2000), modified.

Austria's national-scale carbon research community has not paid adequate attention to the realm of Material Flow Analysis (MFA), which was already quite advanced when the ACDb (and ACBM II) researchers took up their work (e.g., Steurer, 1992; 1994; Hüttler *et al.*, 1996; Payer *et al.*, 1998; Schandl, 1998).[32] It was only recently that the World Resources Institute published a report that compares, for the first time, the environmental policies of five countries, including Austria, based on MFA (Matthews *et al.*, 2000).[33]

Kubeczko (2001a) presents an insightful list that specifies the advantages and disadvantages of using MFA as a basis for carbon flow accounting (see Section 7.1 in his report). Here, it is sufficient to revisit some of these:

<u>Some important advantages:</u>

- Material flow balances are consistent accounts that represent a society's metabolism (anthroposphere). Typically, the material flow balances are compatible with established economic accounts and input-output concepts used to represent the society on the national scale.

[32] Austria, Germany, and Japan were the first countries to establish national material flow balances in the 1990s.
[33] The other four countries are Germany, Japan, The Netherlands, and the USA.

- The boundaries that are used by experts to describe MFA systems and their sub-systems correspond to the social scientists' perception of systems. This helps to derive policy relevant conclusions more readily.

Thus, any national-scale carbon database (or model) that uses MFA — if available — as its basis would benefit in two ways: (1) consistency would come for free as it would have already been achieved, and (2) an interface would become available permitting simple interpretation of the contents of the database (or the model results) in standard socioeconomic terms.

Some important disadvantages:

- MFA covers the anthroposphere. To serve as an adequate basis for carbon flow accounting, MFA would need to be complemented by a module that covers a country's terrestrial biosphere.
- MFA experts typically work with first statistical moments (mean values), not with second statistical moments (uncertainties).
- Material flow balances aggregate flows according to their importance (in terms of material weight). For FCA, a different way of aggregating flows might be necessary that pays attention to their weight in terms of carbon and the associated uncertainties.
- Up to now, material flow balances do not provide detailed information on waste management; they report highly aggregated domestic outflows to air, land, and water.

Thus, it becomes clear that it would have been a task in itself to base FCA, as carried out in the ACDb Study, on an Austrian material flow balance. Figure 17 shows the MFA-FCA compromise that we have realized in the ACDb Study. It is a compromise between what is desirable versus what is currently feasible. For instance, it is desirable to grasp Austria's *metabolism*, here (partially) via the PROD and CONSU/WASTE modules, on the level of material flow accounting,[34] but it is currently not feasible to do the same with the other modules and thus to make full and consistent use of the MFA framework. This would mean, e.g., in the case of the ENERGY module that Austria's FF emissions occur in the CONSU/WASTE module, and thus create considerable confusion for Austrian institutions that have to follow current GHG reporting schemes. It is the PCA communities' perception of systems that hampers the rigorous implementation of MFA based carbon accounting.

However, we hypothesize that MFA based FCA will commonly be performed in the future. Its fundamental advantages outweigh by far its current methodological disadvantages. Austria would have the entire expertise in place to lead this research.

[34] Note that, as a consequence of grasping production, consumption, and waste (including waste management) on the level of material flow accounting, system boundaries are drawn differently in the ACDb compared to the ACBM II. In the latter, the consumption of goods is part of its production system, while in the ACDb the boundaries are drawn between production (PROD) and consumption combined with waste (CONSU/WASTE) (see Figure 16 and also Sections 4.2.2 and 4.2.3).

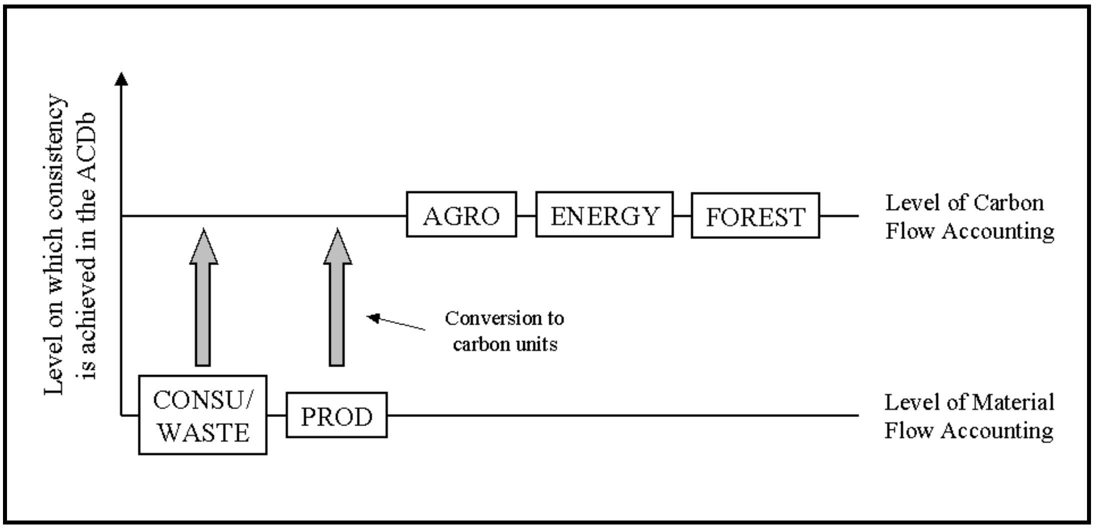

Figure 17: The MFA-FCA compromise realized in the ACDb Study: CONSU/WASTE and PROD reflect Austrian MFA expertise. These modules have been linked on the level of material flow accounting before they have been uplifted to the level of carbon flow accounting. AGRO, ENERGY, and FOREST reflect the expertise that is available at different Austrian institutions (e.g., ENERGY expertise at Austria's Federal Environment Agency). These modules have been treated on the level of material flow accounting, but in isolation, before they have been uplifted to the level of carbon flow accounting, where they have been linked to each other. The final linkage of these two sets of modules, the CONSU/WASTE–PROD set with the AGRO–ENERGY–FOREST set, has then been realized on the level of carbon flow accounting.

4.1.2 Issue 2

The consequence of including uncertainty in the FCA.

Before discussing this issue, it is instructive to go back to Section 2.2.2, where we indicated (1) that we apply the IIASA uncertainty concept, and (2) that the ACDb deals only with existing data, which are available either from *one-sided statistics* (a complementary data set does not exist) or from *two-sided statistics* (a complementary data set exists). As a consequence, the term *uncertainty* **—** which we use exclusively **—** stands, in principle, for random error or (0.5 * uncertainty range) (see also Figure 3). Soft knowledge (measured biases) is generally not considered. For this reason some of the calculated uncertainties can be considered too small. However, they are generally not expected to fall outside their respective uncertainty classes, which we introduce in Section 4.1.3.

We have not yet specified at which level of confidence we want to report uncertainty. For the ACDb we chose the 68% confidence level, because striving for a higher, purely mathematical confidence level cannot be justified physically as long as we have to cope with uncertainty ranges as a result of inconsistent or missing knowledge in realizing full carbon accounts (see Section 4.2).[35]

As indicated in Sections 2.1.4 and 3.1.3, the ACDb pays equal attention to the first (mean values) and second statistical moments (uncertainties) from the very beginning. However, proceeding in this way evokes a conflict (see Figure 18) (confer also Geisler and Jonas (2001), who paid considerable attention to this issue.) Traditionally, researchers (including, e.g., the ACBM II modelers as well as the IIASA researchers conducting the Russian case study) focused mainly on grasping mean values. Their research falls under the purview of complexity, instead of simplification. The researchers resolve more detailed mean values, the more complex the reality appears that they wish to reflect. However, the rigorous consideration of uncertainties on such highly disaggregated levels is — although possible in principal, e.g., with the help of so-called *Monte Carlo* techniques (IPCC, 2000a) — not advisable and requires the opposite, that is, to simplify data (thus, also models), ideally to a level which permits to treat them as statistically independent (or as statistically independent as possible).

In the ACDb Study, we attributed special importance to the direct and transparent understanding of both mean values and uncertainties. In particular, this requirement forced us to agree on a compromise, i.e., on a data aggregation level that permits a balanced treatment of mean values and uncertainties in terms of their thematic resolution. This is the reason why the ACDb does not resolve the lowest aggregation (highest resolution) levels that are realized within the various ACBM II modules (see also Geisler and Jonas, 2001).

However, the possibility exists for comparing different approaches to handle uncertainty. In the context of our work on the ENERGY module (see Section 4.2.5), we demonstrate how a Monte Carlo approach and our less sophisticated approach complement each other and even lead to the same results.

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[35] In accordance with ISO (1995) (see also Taylor and Kuyatt, 1994; NIST, 2001), we distinguish between an uncertainty evaluation of *Type A* and *Type B*. Type A is the evaluation of uncertainty by the statistical analysis of a series of observations. By way of contrast, Type B is the evaluation of uncertainty by means other than the statistical analysis of series of observations.
Thus, in the case of a normal distribution of Type A, a confidence level of ± 68% corresponds to an uncertainty range of ± (1 * standard deviation), called *standard uncertainty* in generalized terms. We follow expert recommendations and define a standard uncertainty of Type B similar to a standard uncertainty of Type A, under the (necessary but not sufficient) assumption that the uncertainty is normally or *close-to-normally* distributed.

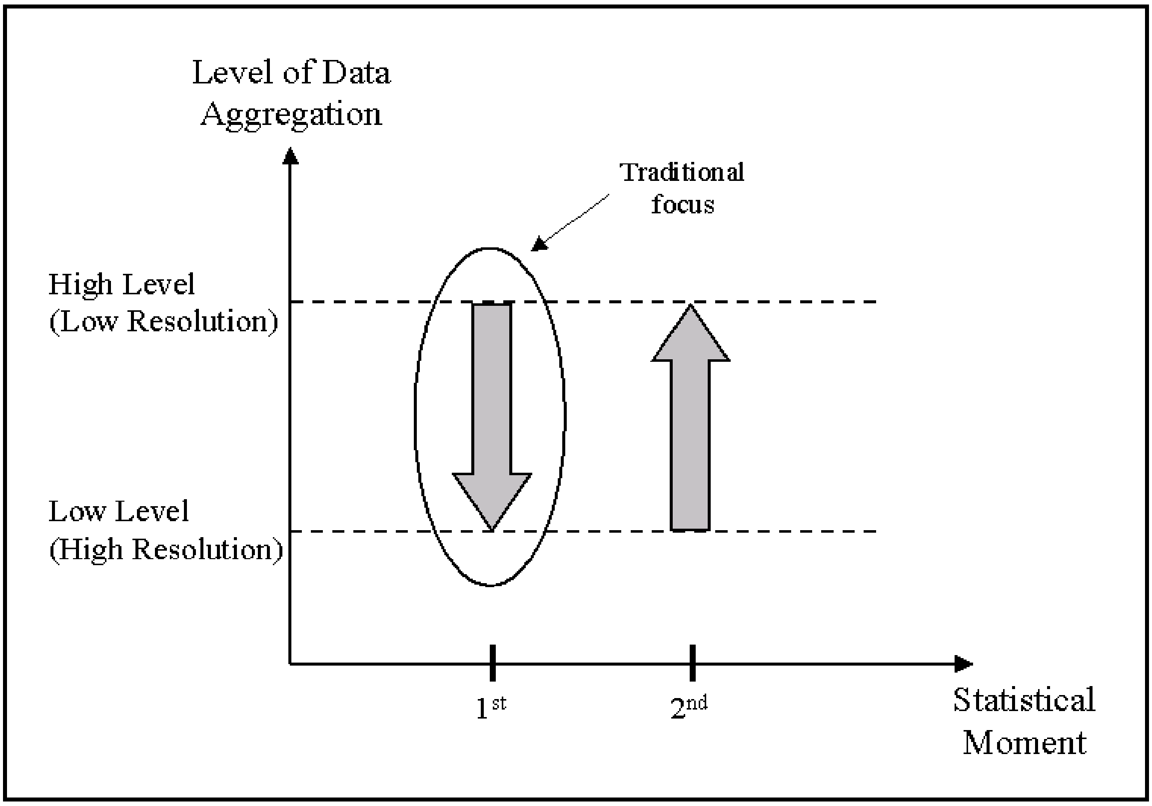

Figure 18: The consequence of including uncertainty in the FCA: The balanced treatment of mean values and uncertainties as described in the text requires the compromise of an appropriate data aggregation (data resolution) level.

4.1.3 Issue 3

The usefulness of the ACDb.

The realization of the previous issue, the balanced treatment of mean values and uncertainties, led us immediately to this issue. In the ACDb, the calculation of uncertainties follows the law of uncertainty (error) propagation, if the data sets can be assumed to be normally or *close-to-normally* distributed and are not correlated among each other. However, this may not always be the case and the need for pragmatic approximations arises. In addition, a great number of cases exist, in which it turns out to be advisable for physical reasons to simplify calculations. We provide a detailed account of all calculations and the quality of our approximations in the technical report, which is published separately.

For the purpose here, it is sufficient to report on the following important observation. We found all our level uncertainty calculations and approximations quite robust (which we will demonstrate in Sections 4.2.1 and 4.2.5 in the context of the FOREST and ENERGY modules). By this we mean that the derivation of aggregated uncertainties is typically not unambiguous and even prone to errors. However, we are confident that other experts, who use our data sets, will estimate uncertainty ranges that overlap ours. However, this may not be true any more if their systems views differ from ours (e.g., by proceeding intra-modular rather than inter-modular). We materialize this by introducing the following relative uncertainty classes (Table 4):

Table 4: Relative uncertainty classes applied in the ACDb.

Class	Relative Uncertainty [%]
1	0 – 5
2	5 – 10
3	10 – 20
4	20 – 40
5	> 40

We interpret these classes qualitatively below (see Section 4.3). Their quantitative understanding is as follows. The definition of the classes is arbitrary and attempts to satisfy simple practical considerations as to how many different resolution intervals we wanted to realize. The classes reflect our physical and systems analytical thinking: For instance, assume that we have derived a relative uncertainty of 13.7% in specifying a carbon pool or flow. We then interpret this value as falling within the respective relative uncertainty class, here 10–20% (class 3).[36]

In contrast, if an expert came up with a value, which would fall outside *our* relative uncertainty class, we would immediately know that something drastic has happened. He/she may have used different initial data, processed them differently or applied a different systems view and the need for explaining these differences would immediately arise. (Of course, this interpretation also requires taking into consideration how close *our* value is to the boundary of a class.)

It was this thinking in terms of relative uncertainty classes, which we used in our communications with national experts and in checking our uncertainty calculations against theirs. Based on our experiences, we strongly recommend the application of relative uncertainty classes as a common good practice measure. The reporting of exact relative uncertainties is not justified in light of the inconsistent accounting of carbon under the Kyoto Protocol (for an illustrative example see the ENERGY module, Section 4.2.5) and the need of coping with uncertainty ranges as a result of inconsistent or missing knowledge (for an illustrative example see the FOREST module, Section 4.2.1). Also, it is this kind of uncertainty information, which one wishes to have at hand initially before going into further analyses, e.g., how individual uncertainties rank relatively to each other in terms of their importance with regard to a total carbon pool or flux estimate.

We will encounter more experiences in the following section. However, we consider them more specific, which is why we report them in the context of the various modules.

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[36] The increasing width of our relative uncertainty classes and our classification of relative uncertainties as unreliable beyond class 3 (see also Table 17) is in agreement with the IPCC (1997a), which advises against the application of the law of uncertainty propagation if the relative uncertainties that are combined under this law are greater than 60% (95% confidence level).

4.2 Specific Experiences and Results

This section gives an overview on the various modules of the ACDb in regard to both specific experiences and results to foster the holistic view. Intra-modular details are given as far as they facilitate a better inter-modular understanding. For additional detail, the reader is referred to the technical report, which is published separately.[37]

The modules are presented in the order of their realization. The FOREST module was realized first. Then the modules PROD and CONSU/WASTE were tackled in parallel to the realization of the modules AGRO and ENERGY. This information on the order of the modules already answers a number of questions. For instance, it explains why we have not used data in realizing a particular module, which only became available later, etc.

Austria is a *data-rich* country, meaning that *one-sided* statistics are available for most of its carbon pools and flows. (The exceptions are specified in Sections 4.2.1 to 4.2.5.) However, in a few cases, even *two-sided* statistics exist. These cases are most interesting because their statistics generally disagree and thus lead to deeper insights with respect to the involved subsystems and uncertainties. Typically, expert review teams that screen country data encounter one-sided statistics (if at all) and *two-sided* statistics only infrequently. Whenever these occur, the tendency to misinterpret such situations is pronounced by questioning the data-statistical quality standards of these countries. However, the opposite seems more likely to be true. Making *two-sided* statistics available must be highly appreciated because the expert review teams receive the rare possibility of scrutinizing the quality of their work and asking themselves what they could not adequately review if countries provided them with only *one-sided* statistics.

In Section 4.1.2 we discussed the issue of the balanced treatment of mean values and uncertainties. In general, this process of finding the appropriate balance required a great deal of scientific considerations rather than following an instructional manual. Nevertheless, we consider the ACDb to be useful to many scientists and other experts, who are involved in national-scale carbon research studies in Austria and elsewhere. The database is transparent (all calculations can directly be followed), clearly structured (see Appendix 1), and all of its entries are well described.

As mentioned in Sections 2.2.2 and 4.1.2, the ACDb only deals with existing data. Soft knowledge (measured biases) is generally not considered. This also means that uncertainties are only considered if they are available or could be derived. This is an additional reason why some of the calculated uncertainties can be considered too small. However, we generally do not expect them to fall outside their respective relative uncertainty classes introduced in Section 4.1.3. We recapitulate this in order to make a reader of the study or a user of the ACDb aware of where we currently stand with our efforts of grasping Austria's national-scale uncertainties. An even more comprehensive picture can be gained if we place the ACDb into the context of the VT concept (see also Figure 19).

[37] The modules CONSU/WASTE and PROD are completely described by Kubeczko (2001a).

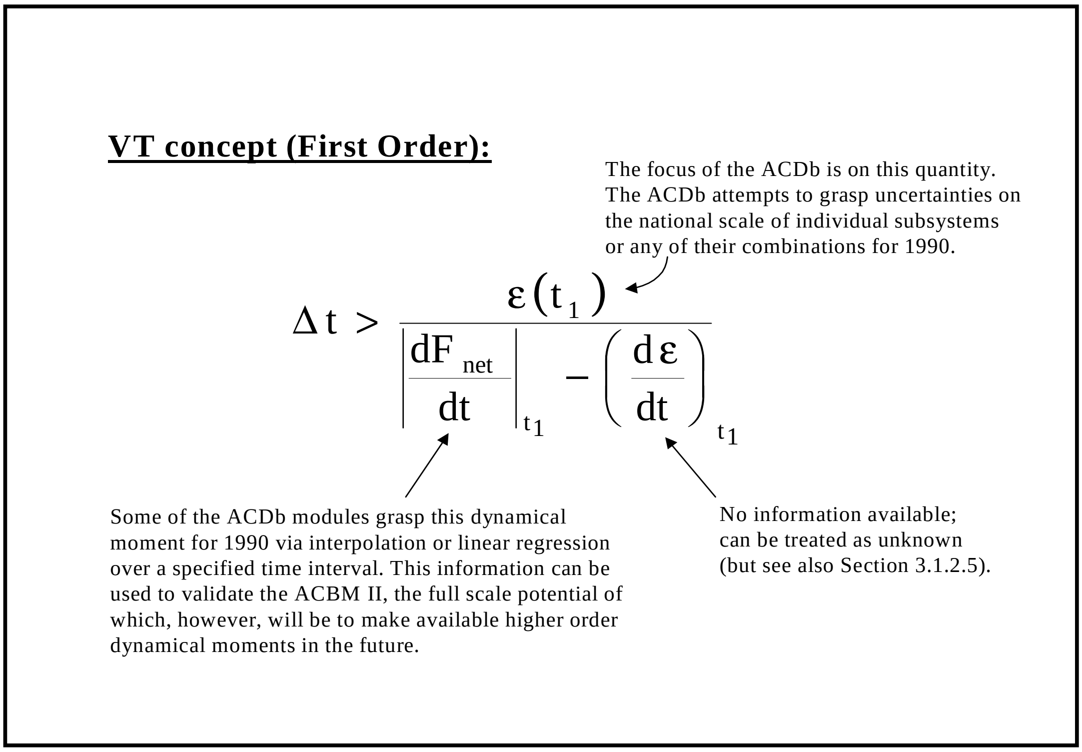

Figure 19: The ACDb placed into the context of the (here: first order) VT concept [see Equation (4-3)].

4.2.1 FOREST

This section summarizes our specific experiences in setting up the FOREST module and its results. This module was realized first and its results were used within the ACBM II. A general overview of the module's basic characteristics is given in Table 5. We discuss the most important ones below. In so doing, we also mention a noteworthy Austrian study (Weiss *et al.*, 2000) that was published in the meantime. The general comparison of our results with those of the study is most insightful as it demonstrates the need of using uncertainty ranges as a result of inconsistent or missing knowledge but, concomitantly, the robustness of calculating uncertainties if the notion of relative uncertainty classes is adopted.

The main data sources used by the FOREST module are the Austrian Forest Inventories (AFIs) 1986/90 and 1992/96, the Austrian Wood Balance (AWB) 1988–1994, and Körner *et al.* (1993). The latter is a biomass study and provides, among other things, soil carbon density data that are not exclusively specific for Austria.[38] We made use of these data because BORIS, the Austrian soil database, which is also comprised of the Austrian Forest Soil Inventory (AFSI), was in the latter stages of completion at Austria's Federal Environment Agency (FEA). At that time, it was too early to use BORIS in this Study.

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[38] For completeness, it is mentioned that the uncertainties, which Körner *et al.* (1993) report for their soil carbon density data, are incorrect and required correction.

Bearing in mind that the ACDb had to provide support to the ACBM II (see Section 2.1.6), it is conditional that it strived for inter as well as intra-modular consistency. To this end, two major statistical inconsistencies had to be overcome by applying the IIASA uncertainty concept. The first relates to the exploitation-harvest discrepancy between the AFI and AWB, most likely due to the way derbholz is considered in the two statistics (Jonas, 1997; Weiss *et al.*, 2000).[39] The second ensures that the physical law of conservation of matter *(temporal change in standing stock[40] = net growth - adjusted exploitation)* is fulfilled (Jonas, 1997).

Table 5: Basic characteristics of the ACDb FOREST module.

Module	**FOREST**
File Name	forest.xls
Thematic Coverage	1. Austria's exploitable forest and its soils (0–50 cm) 2. Austria's wood supply (including fuelwood from non-forest floor) and utilization
Consistency	Intra-modular consistency on the level of material flow accounting
Integration	Linkages to other modules on the level of carbon flow accounting
Main Data Sources	1. Austrian Forest Inventories (AFIs) 1986/90 and 1992/96; soil related data from Körner *et al.* (1993) 2. Austrian Wood Balance (AWB) 1988–1994
Temporal Coverage	1988–1994 (except for soil carbon calculations) Soil carbon: 1990
Temporal Resolution	Annual (via interpolation and linear regression)
Thematic Resolution	1. Tree species for AFI and soil related data 2. Standard supply and utilization categories for AWB data
Spatial Reference	Data are aggregated into a tabular form and not geo-referenced
Titles of Worksheets	1. General 2. AWB-AFI Consistency 3. C Conversion + Expansion 4. Austria's Wood Balance 5. Veg + Soil Pools 6. Harvest Residues 7. Bridge to ACBM II
Major Inconsistencies to Overcome	AFI (exploitation) ↔ AWB (domestic supply) Temporal change in standing stock ↔ Net increment - (adjusted) Exploitation
Major Data Limitations	NPP: Systematic measurements/assessments are not available. Soil including litter: So far, national-scale measurements were carried out only once under the Austrian Forest Soil Survey (AFSI). Soil respiration: Site data exist but have not yet been upscaled to the national scale. Carbon conversion factors are not exclusively specific for Austria (see also Weiss *et al.*, 2000)
Bridge to ACBM II	Provided (see Worksheet 7)

[39] According to the AFI, derbholz reveals a diameter over bark of ≥ 7 cm.

[40] Throughout the Study the term "*standing stock*" is used for *Vorrat*, which includes the stems (without branches) of all standing trees (living or dead), measured over bark, with a diameter at breast height (DBH) ≥ 5 cm (e.g., FMAF, 1998).

The pools and fluxes of the FOREST module are specified in Figures 20 and 21 (see also Tables 6 and 7), where the latter figure largely reflects the AWB.[41] Figure 22 shows Figure 21 after adjustment to meet the structural requirements of the ACBM II. The module's overall carbon balance is summarized in Figure 23. In these figures, modules and carbon pools are specified as boxes, carbon fluxes as arrows, and flux balanced nodes as hexagons. These elements appear dotted if they are outside the actual balancing sphere.

Several major data limitations exist that prevent the complete realization of the FOREST module solely based on measured data. The first — no knowledge on changes in soil carbon — reflects the fact that national-scale soil measurements have only been carried out once so far under the AFSI (e.g., Weiss *et al.*, 2000). The second — inadequate knowledge of soil respiration — is due to the fact that it still remains to be tested whether available site data can be upscaled to the national scale (Zechmeister-Boltenstern, 2001).

Also, the ACDb does not model and can, therefore, not derive Net Pimary Production (NPP), a quantity that is difficult to assess systematically. However, recognizing that the NPP is a quantity of paramount importance, the ACDb specifies, by way of exception, the NPP of Austria's exploitable forest as the mean value (= 13.9 tC yr^{-1}; relative uncertainty class 5) of three quite distinct model results, including that of the ACBM II.[42] We then estimated forest soil respiration (= 7.7 tC yr^{-1}; relative uncertainty class 5) by balancing the following three net carbon fluxes: NPP, adjusted exploitation, and forest sink strength (see Figure 20). The latter is slightly increased by following Weiss *et al.* (2000) to also account for the sink strength of the forest soil.[43]

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[41] Bark is only used to generate energy. To simplify the carbon accounting of residual wood flows in Figure 21, *Bark* is directed to *Fuelwood (including ∆Storage)* instead of *Residual Wood*, under which it is accounted in the AWB.

[42] Jonas (1997) derives 22.0 tC yr^{-1} using the ACBM I, while Orthofer *et al.* (2000) find 12.3 tC yr^{-1} using the ACBM II. Hasenauer *et al.* (1999a, b) employ an ecosystem model, with the help of which they derive an NPP of ~ 442 g dm m^{-2} yr^{-1} or 7.4 tC yr^{-1} (where we use: 0.5 tC (t dm)$^{-1}$ for the carbon content and 3.338 10^6 ha for the area of Austria's exploitable forest).

[43] For the balancing, we used: NPP (see Figure 20 and Footnote 42): 13.9 10^6 tC yr^{-1} (class 5); adjusted exploitation (see Figure 20 and Table 6): 3.73 10^6 tC yr^{-1} (class 3); forest sink strength (see Figure 20 and Table 8): 2.2 10^6 tC / yr (class 5); and the soil sink strength reported by Weiss *et al.* (2000) (see Table 8): 0.3 10^6 tC / yr (± 0%).

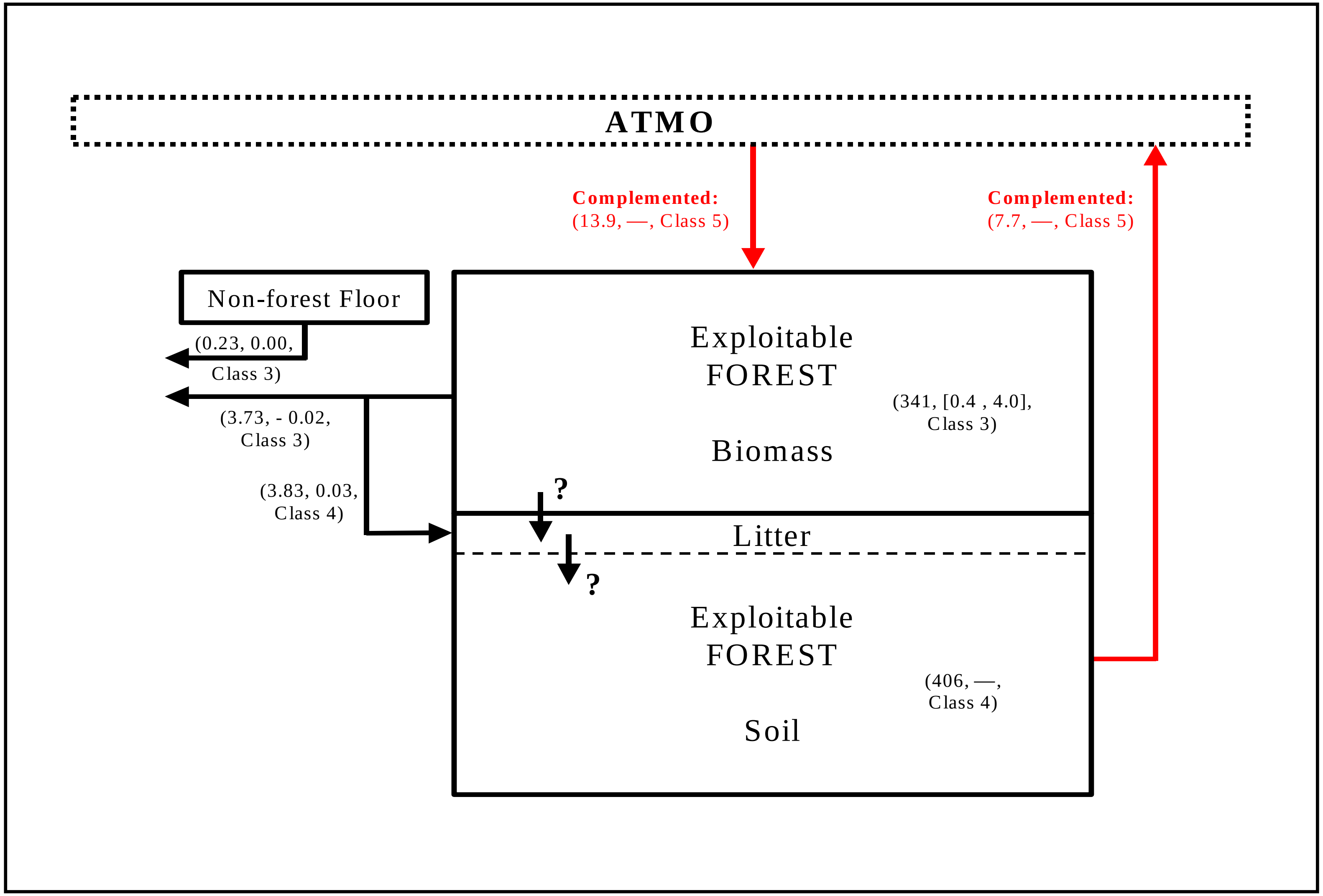

Figure 20: ACDb FOREST module: 1990 pools and fluxes, each of them characterized by two numbers and an uncertainty: 1990 mean, 1990 trend, and the relative uncertainty class underlying the 1990 mean. See Table 6 for units.

Table 6: Table to Figure 20. For the complemented data see text.

Available Data					
Pool			**1990 Mean 10^6 tC**	**1990 Trend 10^6 tC / yr**	**Uncertainty**
Biomass			341	[0.4 , 4.0]	Class 3
Soil (including litter; 0–50 cm)			406	---	Class 4
Flux	**Origin**	**Destination**	**1990 Mean 10^6 tC yr^{-1}**	**1990 Trend 10^6 tC yr^{-1} / yr**	**Uncertainty**
Total Domestic Supply (excluding Fuelwood from Non-forest Floor and Re-used Waste wood)	Exploitable Forest: Biomass	Domestic Supply from Forest Floor and Other Domestic Supply (excluding Fuelwood from Non-forest Floor)	3.73	-0.02	Class 3
Fuelwood from Non-forest Floor	Non-forest Floor (outside exploitable forest)	Other Domestic Supply: Fuelwood from Non-forest Floor	0.23	0.00	Class 3
Harvest Residues	Exploitable Forest: Biomass	Litter Pool of the Soil Pool	3.83	0.03	Class 4
Complemented Data					
Flux	**Origin**	**Destination**	**1990 Mean 10^6 tC yr^{-1}**	**1990 Trend 10^6 tC yr^{-1} / yr**	**Uncertainty**
Net Primary Production	Atmosphere	Exploitable Forest	13.9	---	Class 5
Heterotrophic Respiration	Soil Pool (including litter pool)	Atmosphere	7.7	---	Class 5

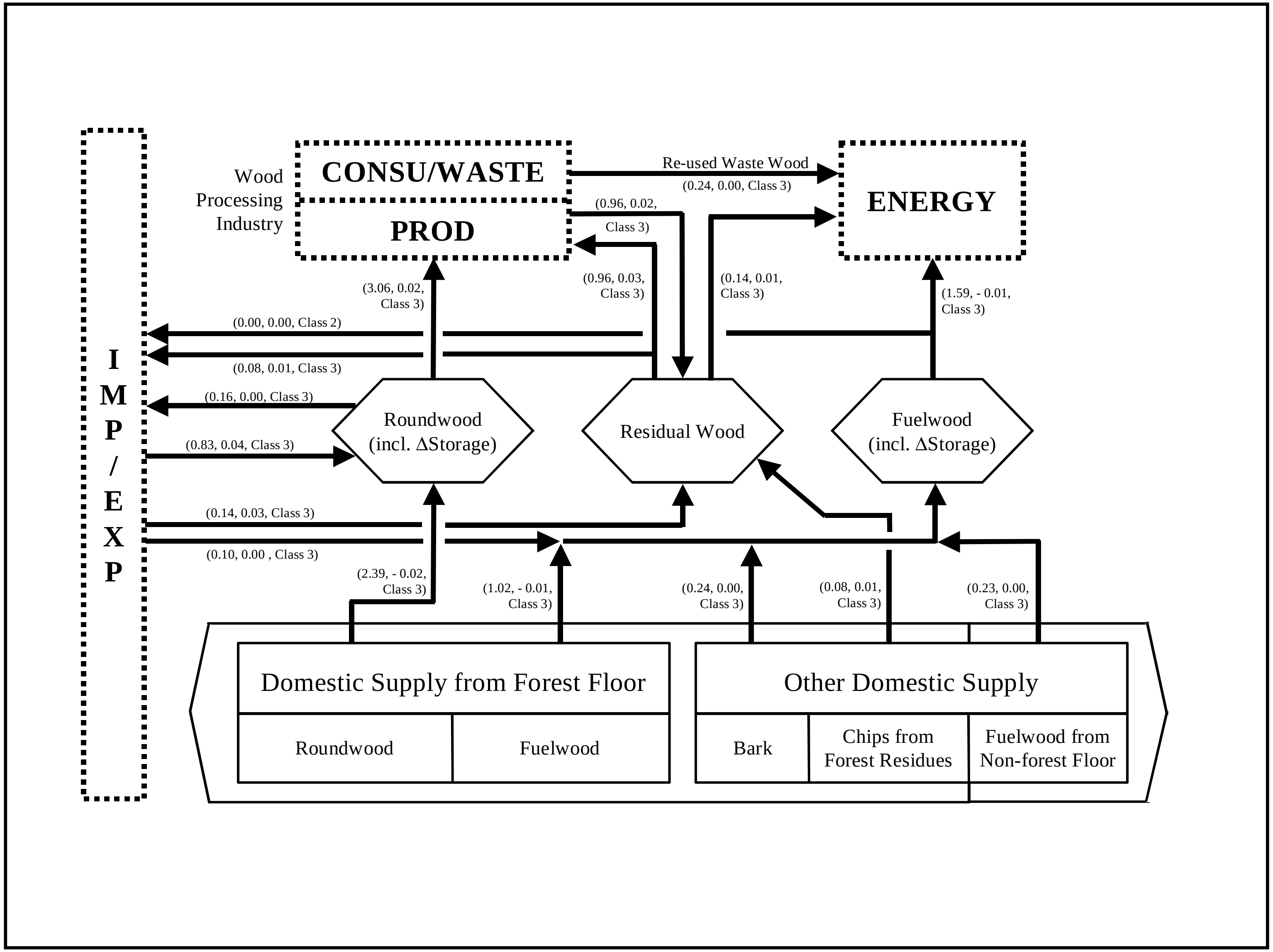

Figure 21: ACDb FOREST module: 1990 fluxes, each of them characterized by two numbers and an uncertainty specification: 1990 mean, 1990 trend, and the relative uncertainty class underlying the 1990 mean. See Table 7 for units.

Table 7: Table to Figure 21.

Available Data					
Flux	**Origin**	**Destination**	**1990 Mean 10^6 tC yr^{-1}**	**1990 Trend 10^6 tC yr^{-1} / yr**	**Uncertainty**
Domestic Wood Supply:					
Domestic Roundwood Supply from Forest Floor	Domestic Supply from Forest Floor: Roundwood	Roundwood (including ΔStorage)	2.39	- 0.02	Class 3
Domestic Fuelwood Supply from Forest Floor	Domestic Supply from Forest Floor: Fuelwood	Fuelwood (including ΔStorage)	1.02	- 0.01	Class 3
Domestic Supply of Bark	Other Domestic Supply: Bark	Fuelwood (including ΔStorage)	0.24	0.00	Class 3
Fuelwood from Non-forest Floor	Other Domestic Supply: Fuelwood from Non-forest Floor	Fuelwood (including ΔStorage)	0.23	0.00	Class 3
Domestic Supply of Chips from Forest Residues	Other Domestic Supply: Chips from Forest Residues	Residual Wood	0.08	0.01	Class 3
Import/Export:					
Import of Roundwood	IMP/EXP	Roundwood (including ΔStorage)	0.83	0.04	Class 3
Export of Roundwood	Roundwood (including ΔStorage)	IMP/EXP	0.16	0.00	Class 3
Import of Fuelwood	IMP/EXP	Fuelwood (including ΔStorage)	0.10	0.00	Class 3
Export of Fuelwood	Fuelwood (including ΔStorage)	IMP/EXP	0.00	0.00	Class 2
Import of Wood Chips	IMP/EXP	Residual Wood	0.14	0.03	Class 3
Export of Wood Chips	Residual Wood	IMP/EXP	0.08	0.01	Class 3
Wood Utilization (excluding Export):					
Roundwood for Wood Processing (including ΔStorage)	Roundwood (including ΔStorage)	PROD	3.06	0.02	Class 3
Fuelwood and Bark for Energetic Utilization (including ΔStorage)	Roundwood (including ΔStorage)	ENERGY	1.59	- 0.01	Class 3
Wood Residues for Wood Processing (including ΔStorage)	Residual Wood	PROD	0.96	0.03	Class 3
Wood Residues (excluding Bark) for Energetic Utilization (including ΔStorage)	Residual Wood	ENERGY	0.14	0.01	Class 3
Wood residues Corrected for Double Accounting	PROD	Residual Wood	0.96	0.02	Class 3
Re-used Waste Wood	CONSU/WASTE	ENERGY	0.24	0.00	Class 3

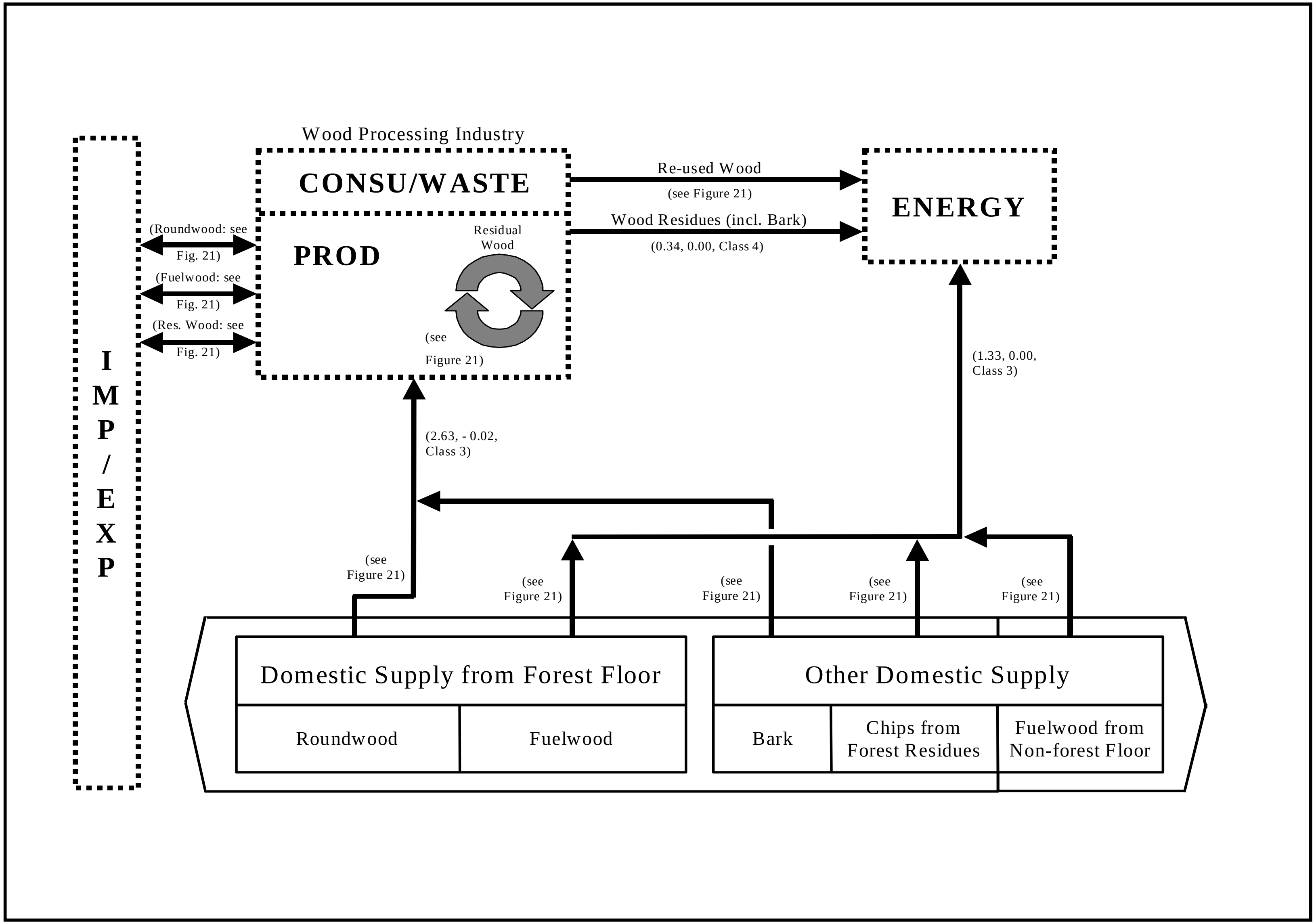

Figure 22: Figure 21 adjusted to meet the structural requirements of the ACBM II.

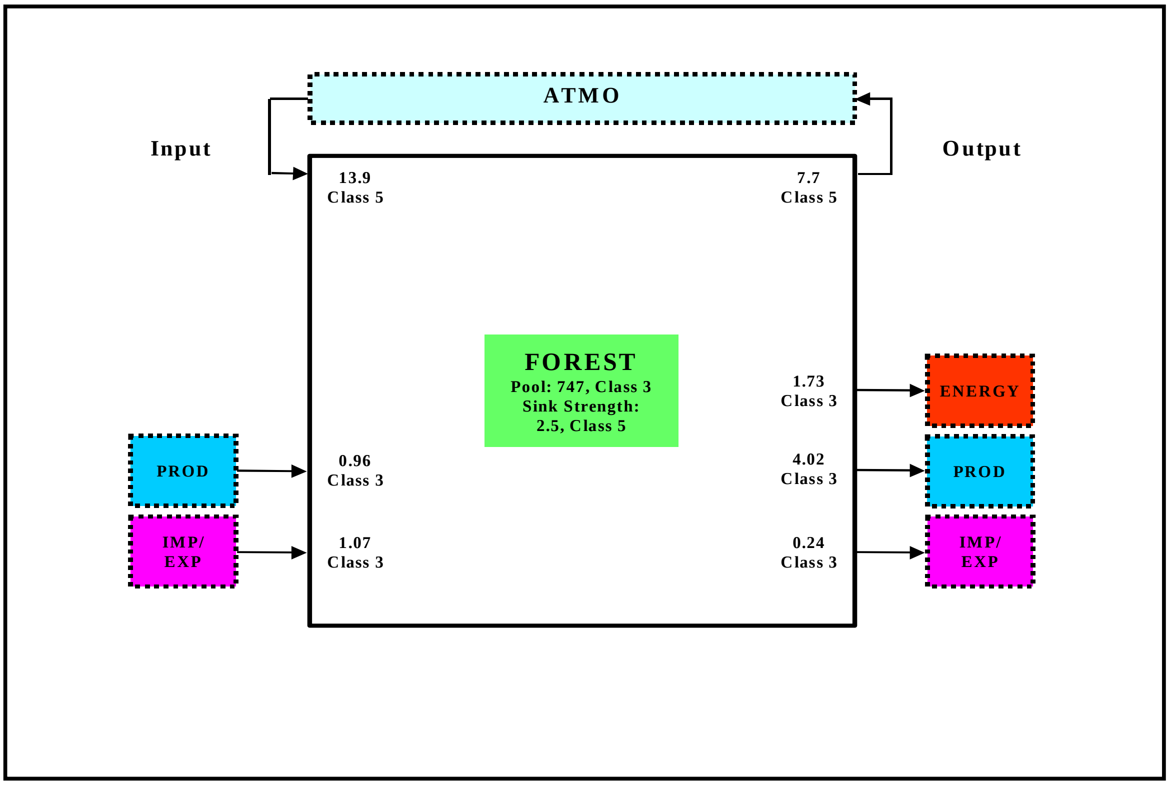

Figure 23: ACDb FOREST module (1990): The module's setting within the ACDb, which is derived by aggregating Figures 20 and 21. Unit of pools: 10^6 tC; unit of fluxes and pool changes: 10^6 tC yr^{-1}.[44]

Table 8 provides a general comparison of our FOREST pool and sink strength results with those of Weiss *et al.* (2000).[45] Three important observations can be made:

1. Weiss *et al.* (2000) apply a more sophisticated approach than we do to derive whole-tree related factors converting biomass (in m^3 o.b. stem wood) to carbon (in tC) separately for standing stock, net growth, and exploitation. We only derive one conversion factor based on standing stock and apply it also to the conversion of net growth and exploitation.[46] The various conversion factors differ slightly (ours is slightly greater than those of Weiss *et al.*), but all of them reveal the same relative uncertainty class (i.e., class 3). (This also explains the class 3 entries in Tables 6 and 7.)

   It is this small difference in the mean values, which crucially determines by how much carbon calculations differ. However, the application of uncertainty ranges introduces robustness into these calculations as these ranges typically overlap each

[44] To balance the ACDb FOREST module shown in Figure 23, the FOREST → ENERGY flux (1990: 1.73 10^6 tC) has to be decreased by the amount of fuelwood from non-forest floor (1990: 0.23 10^6 tC).
[45] A detailed comparison between the ACDb's FOREST module and the study of Weiss *et al.* (2000) is presented in the technical report of the ACDb.
[46] We advocate here the use of the methodology developed by Weiss *et al.* (2000) over ours. However, it remains to be tested how sensitive their methodology is to input values that are limited in terms of availability, thus resulting in numerical instabilities.

other. This tendency towards robustness increases with aggregation (e.g., by combining the vegetation and soil pools).

2. In deriving the sink strength of Austria's exploitable forest, Weiss *et al*. (2000) overcame the exploitation-harvest discrepancy between the AFI and AWB by increasing uncertainties pragmatically, while we applied the IIASA uncertainty concept. In addition, we applied this concept also to another statistical inconsistency, namely between *temporal change in standing stock* and *net growth-adjusted exploitation* (see also Table 5). By way of contrast, Weiss *et al.* followed another (legitimate) approach, which also covers a longer time period around 1990. They assigned an uncertainty to the term *net growth-(pragmatically) adjusted exploitation* (integrated from 1961 to 1996), but did not do so to the *1961–1996 change in standing stock*. (However, although not mentioned in their study, Weiss *et al.* made sure that the *1961–1996 change in standing stock* falls within the uncertainty of this term.)

   It is this difference in systems views, which (1) renders a direct comparison of uncertainties difficult, and (2) determines the different relative uncertainty classes that Weiss *et al.* and we assign to the forest sink strength (Weiss *et al.*: class 4; we: class 5).[47] This finding seems to be generalizable as we can make a similar observation based on the comparison of results for the ENERGY module (see Section 8.5), leading us to the fundamental question how meaningful are uncertainties in the context of the Kyoto Protocol that are derived based on non-standardized systems views or with the help of *one-sided* statistics?

3. The accounting of LULUCF activities under the Kyoto Protocol follows, in principle, the *temporal change in standing stock*, i.e., the left side of the law of conservation of matter (see Appendix 2). It is this side of the equation, which reveals the greater uncertainty, potentially even greater than 100% (if nonpermanent survey plots are used that do not permit the reduction of uncertainty due to correlation): Two great numbers are subtracted from each other and the associated uncertainty is related to the resulting difference. As a consequence, the *temporal change in standing stock* can be negligible, but potentially also twice as great as the mean *temporal change in standing stock* itself. The implications of this are essentially unexplored with respect to Articles 3.3 and 3.4 of the Protocol but may be crucial for their implementation.

[47] However, it is noted that we also derive the relative uncertainty class 4 for the sink strength of Austria's exploitable forest if we don't request the *two-sided* treatment of the second statistical inconsistency (*temporal change in standing stock* ↔ *net growth-adjusted exploitation*) in terms of uncertainties and use only its right side for the calculation of uncertainty.

Table 8: General comparison: ACDb FOREST module and Weiss *et al.* (2000) (WEA in this table).[45] Additional information by Weiss (2001).

	ACDb: FOREST	Weiss *et al.* (2000) [WEA]
	Pools	
Scope	Austria's exploitable forest: (3.338 ± 0.044) 10^6 ha	Austria's entire forest: (3.893 ± 0.046) 10^6 ha
	Total (Above and Belowground) Biomass	
Principal Calculation	The approach applied by FOREST is similar to that applied by WEA. The following two steps are carried out: (1) Data processing to linearly interpolate area (exploitable forest) and standing stock (exploitable forest) (the AFIs 1986/90 and 1992/96 are used); (2) conversion from biomass (m^3 o.b.) to carbon units (tC).	The approach applied by WEA is similar to that applied by WEA. They carry out the following three steps: (1) Data processing to linearly interpolate areas (exploitable forest, protection forest without yield) and standing stock (exploitable forest) (the AFIs 1986/90 and 1992/96 are used); (2) conversion from biomass (m^3 o.b.) to carbon units (tC); 3) estimating the carbon content of Austria's protection forest without yield based on Austria's protection forest with yield.
	With respect to Step 2, the conversion from biomass to carbon, FOREST and WEA essentially use identical literature sources providing data that are not exclusively specific for Austria, but process the data differently. For Austria's exploitable forest:	
	Coniferous trees: 0.32 tC / m^3 o.b. Deciduous trees: 0.49 tC / m^3 o.b. Mean: 0.35 tC / m^3 o.b. Uncertainty: [- 15% , + 20%]	Coniferous trees: 0.30 tC / m^3 o.b. Deciduous trees: 0.39 tC / m^3 o.b. Mean: 0.31 tC / m^3 o.b. Uncertainty: ± 13%
Result	Pool for 1990 (based on linear interpolations for 1988–1994) 341 10^6 tC Uncertainty range: [291 , 408] 10^6 tC Uncertainty: [- 15% , + 20%]	Pool for 1990 (based on linear interpolations for 1986/90–1992/96) 320 10^6 tC Uncertainty range: [278 , 382] 10^6 tC Uncertainty: ± 13%
	Soil Carbon (0–50 cm)	
Principal Calculation	The Austrian soil database BORIS, which is also comprised of the AFSI, was in the latter stages of completion. At that time, it was too early to use BORIS in this Study. Thus, FOREST takes soil carbon densities from Körner *et al.* (1993) and areas of tree species from the AFIs 1986/90 and 1992/96.	WEA apply an approach, which is similar to the approach that is applied in the ACDb's AGRO module: The AFSI measures the total organic carbon (TOC) of the organic horizons correctly in terms of volume, but not of the mineral soil layer. The latter is derived with the help of various approximations.
Result	Pool for 1990 (based on linear interpolations for 1988–1994) 406 10^6 tC Uncertainty range: [301 , 512] 10^6 tC Uncertainty: ± 26%	Pool for 1990 (based on linear interpolations for 1986/90–1992/96) 463 10^6 tC Uncertainty range: [278 , 648] 10^6 tC Uncertainty: ± 40%
Total: Entire Forest (including adjustments and/ or corrections)	For the purpose of comparison, adjusted by way of areal interpolation for Austria's entire forest (over-estimate) for 1990: **(398 + 474) 10^6 tC = 872 10^6 tC** Uncertainty range: **[736 , 1018] 10^6 tC** Uncertainty: **[- 16%, + 17%]**	For 1990, where the uncertainty related to soil carbon decreases to ± 25% (Englisch and Weiss, 2001): **783 10^6 tC** Uncertainty range: **[660 , 906] 10^6 tC** Uncertainty: **± 16%**
	Fluxes	
Scope	Austria's exploitable forest: (3.338 ± 0.044) 10^6 ha	Austria's exploitable forest: (3.338 ± 0.044) 10^6 ha Austria's non-exploitable forest is assumed to be in equilibrium.

Table 8: Continued.

	ACDb: FOREST	Weiss *et al.* (2000) [WEA]
	Total (Above and Belowground) Forest Sink Strength	
Principal Calculation	The approach applied by FOREST is different from that applied by WEA. Two major inconsistencies are overcome by applying the IIASA uncertainty concept to ensure inter-modular consistency. The following four steps are carried out: (1) Data processing to harmonize the AFI (exploitation) with the AWB (domestic harvest); (2) conversion from biomass (m^3 o.b.) to carbon units (tC); (3) deriving a carbon consistent AWB that links to PROD and ENERGY; (4) calculating a forest sink strength, which ensures that the law of conservation of matter *(temporal change in standing stock = net growth - adjusted exploitation)* is fulfilled.	The approach applied by WEA is different from that applied by FOREST. They carry out the following three steps: (1) Data processing to support annual calculations (missing data are complemented); (2) conversion from biomass (m^3 o.b.) to carbon units (tC); (3) calculating a forest sink strength on the basis of *net growth - exploitation*. It is in combination with Step 2, where WEA increase uncertainties pragmatically to achieve consistency with the AWB. Not mentioned in their study, but WEA check, in combination with Step 3, whether the *1961–1996 change in standing stock* falls within the uncertainty that underlies their *net growth-(pragmatically) adjusted exploitation* (integrated from 1961 to 1996).
	With respect to Step 2, the conversion from biomass to carbon, FOREST and WEA essentially use identical literature sources providing data that are not exclusively specific for Austria, but process the data differently. For Austria's exploitable forest:	
	See above under pools.	Mean annual values for 1986–1996: Net growth: 0.30 tC / m^3 o.b. ± 13% Exploitation: 0.31 tC / m^3 o.b. ± 13%
Result	Sink strength for 1990 (based on linear interpolations for 1988–1994) 2.2 10^6 tC Uncertainty range: [0.4 , 4.0] 10^6 tC Uncertainty: ± 82%	Mean annual sink strength for 1961–1996: 2.5 10^6 tC (for the individual years: [1.0 , 3.7] 10^6 tC) Uncertainty range: [1.8 , 3.3] 10^6 tC (for the individual years: not specified) Uncertainty: ± 30% (for the individual years: [between ± 20% , between ± 74%]
	Soil Sink Strength	
Principal Calculation	Not calculated: (1) The AFSI was carried out only once so far; and (2) the ACDb does not apply diagnostic modeling.	WEA apply conceptional modeling.
Result	--- (see Table 5)	Mean annual sink strength for 1961–1996: 0.3 10^6 tC Uncertainty range: not specified Uncertainty: not specified
Total: Exploitable Forest (approximated)	See forest sink strength for 1990 (based on linear interpolations for 1988–1994) **2.2 10^6 tC** Uncertainty range: **[0.4 , 4.0] 10^6 tC** Uncertainty: **± 82%**	Mean annual sink strength for 1961–1996: **2.8 10^6 tC** Uncertainty range: **[2.1 , 3.6] 10^6 tC** Uncertainty: **± 30%**

4.2.2 PROD

This module is completely described by Kubeczko (2001a). Therefore, this section can be brief in summarizing the experiences in setting up the module and its results.

A general overview on the modul's basic characteristics is given in Table 9 and the module's overall carbon balance is shown in Figure 24. Kubeczko summarizes his experiences in setting up this (and the CONSU/WASTE) module in his study (see his table in Section 7.1), the most important of which we have already mentioned in Section 4.1.1. With respect to PROD and CONSU/WASTE, Kubeczko presents additional reasons, why an MFA based FCA should commonly be performed in the future and why PROD and CONSU/WASTE should be separated:

- The problem of double accounting has already been solved on the level of material flow accounting before (here) PROD and CONSU/WASTE are uplifted to the level of carbon flow accounting.
- From a socioeconomic perspective, bearing in mind policy conclusions, the consideration of the consumption of goods as a sub-category of PROD to buffer production and waste flows (as realized in the ACBM II) is unsatisfactory. Knowing the emissions from consumption is at least as important as knowing the emissions from waste treatment. To subsume consumption under PROD would, therefore, veil the real hierarchy of important categories.

4.2.3 CONSU/WASTE

This module is completely described by Kubeczko (2001a). A general overview on the module's basic characteristics is given in Table 10 and the module's overall carbon balance is shown in Figure 25. Otherwise see Section 4.2.2.

4.2.4 AGRO

This section summarizes our specific experiences in setting up the AGRO module and its results. A general overview of the module's basic characteristics is given in Table 11. Its structure is given in Figure 26 (see also Table 12), which also specifies the module's pools and fluxes. It slightly deviates from the module structure that has been realized in the ACBM II shown in Figure 27. Two reasons exist for this: (1) Data inadequacy (e.g., with respect to the supply and use of compost and garden crops for private consumption); and (2) comparability with the Revised 1996 IPCC GHG Guidelines (IPCC, 1997a, b, c) (e.g., we account CH_4 emissions from manure management under Husbandry, not under Manure, and also consider the on-site burning of straw). The module's overall carbon balance is shown in Figure 28.

We made use of many data providers, the first being Statistics Austria (formerly Austrian Central Statistical Office), and numerous expert contributions and specific data sources, including BORIS. To realize this module was laborious because of its complicated flow pattern and the many small flows. Concomitantly, we tackled the problem of areal inconsistency in this module, that is, between Austria's LUC classes and Austria's total area on the one hand (see also Appendix 3) and between the resolved agricultural areas and their respective LUC classes on the other hand.[48]

[48] The areas of the FOREST module are considered to be reliable and were, therefore, not subjected to the areal consistency adjustment.

Table 9: Basic characteristics of the ACDb PROD module (Kubeczko, 2001b).

Module	PROD
File Name	prod.xls
Thematic Coverage	Austria's production processes (excluding process energy)
Consistency	Inter-modular consistency (PROD ↔ CONSU/WASTE) on the level of material flow accounting
Integration	Linkages to other modules on the level of carbon flow accounting
Main Data Sources	Relevant studies related to the MFA of Austria, of which the sub-balances for fossil fuels, minerals and biomass are used, taking three life cycle stages into account: primary extraction/imports, processing and final demand: Hüttler *et al.* (1996), Fehringer *et al.* (1997), Schandl (1998). Additional data sources: ISIS database of Statistics Austria (formerly Austrian Central Statistical Office) and other ACDb modules.
Temporal Coverage	1990
Temporal Resolution	Annual
Thematic Resolution	Wood processing Food and feed processing Chemical production Steel production Cement and lime production
Spatial Reference	Data are aggregated into a tabular form and not geo-referenced.
Titles of Worksheets	**1.** General **2.** Austria's Production Balance **3.** Uncertainties and Aggregation **4.** I. Wood Proc + III. Chem Prod **5.** II. Food and Feed Processing **6.** V. Cement and Lime Production **7.** Uncertainty Calculation **8.** MFA 90-92 Mineral **9.** MFA 90-92 Biomass **10.** MFA 90-92 Fossil
Major Inconsistencies to Overcome	Difference in system boundaries: MFA ↔ carbon flow accounting Difference in weighing flows: In *material flow framework*: According to weight ↔ In *carbon flow framework*: According to carbon.
Major Data Limitations	MFA data are not available for small flows. The complexity of the production processes requires major aggregation efforts for their realization in a carbon flow framework.
Bridge to ACBM II	On the aggregation level of PROD and CONSU/WASTE. As a consequence of grasping production, consumption and waste (including waste management) on the level of MFA, system boundaries are drawn differently in the ACDb compared to the ACBM II. In the latter the consumption of goods is part of its production system, while in the ACDb the boundaries are drawn between production (PROD) and consumption combined with waste (CONSU/WASTE).

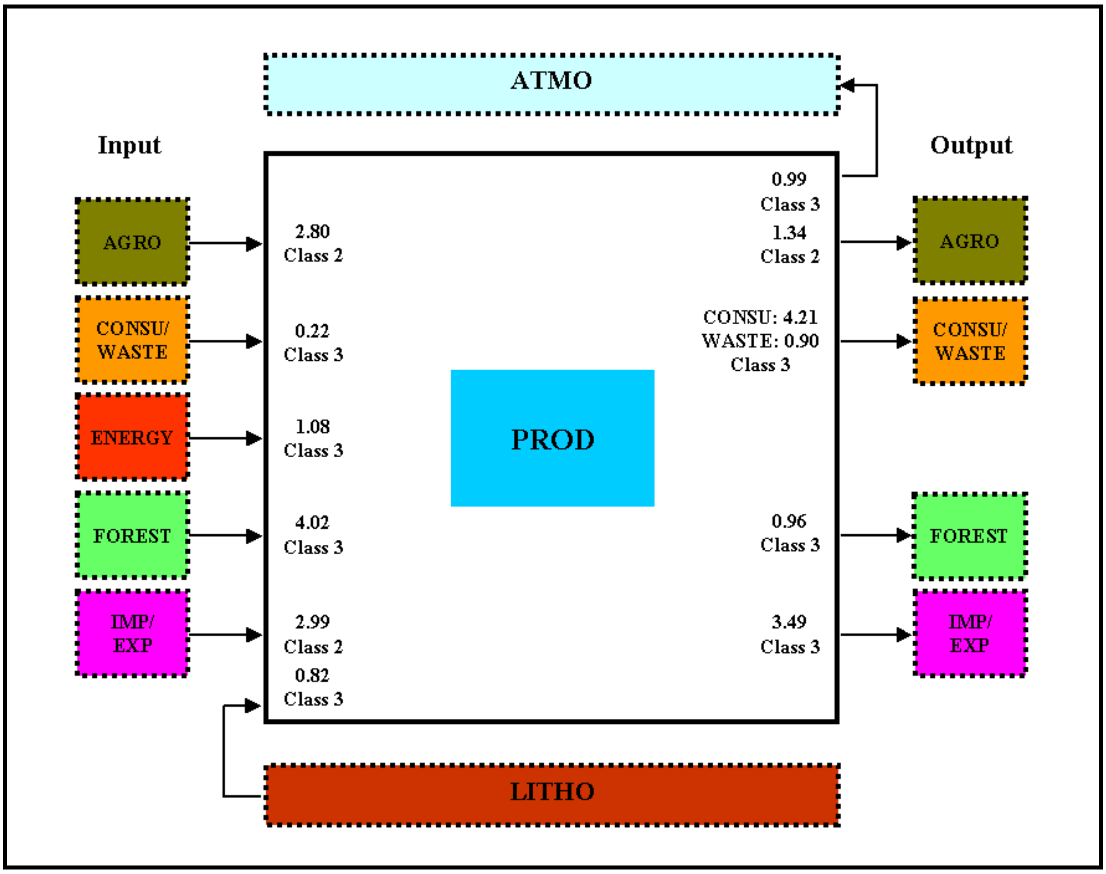

Figure 24: ACDb PROD module (1990): The module's setting within the ACDb. Unit of fluxes: 10^6 tC yr^{-1}. Source: Kubeczko (2001a), modified.

Table 10: Basic characteristics of the ACDb CONSU/WASTE module (Kubeczko, 2001b).

Module	**CONSU/WASTE**
File Name	consuwaste.xls
Thematic Coverage	Austria's consumption and waste flows
Consistency	Inter-modular consistency (CONSU/WASTE ↔ PROD) on the level of material flow accounting
Integration	Linkages to other modules on the level of carbon flow accounting
Main Data Sources	Relevant studies related to the MFA of Austria, of which the low-resolved sub-balances for air and water are used: Krammer *et al.* (1995), Hüttler *et al.* (1996), Matthews *et al.* (2000).
Temporal Coverage	1990
Temporal Resolution	Annual
Thematic Resolution	Wood utilization Food supply Plastic and chemicals
Spatial Reference	Data are aggregated into a tabular form and not geo-referenced.
Titles of Worksheets	**1.** General **2.** Austria's Consu-Waste Balance **3.** Uncertainties and Aggregation **4.** C Conversion + Expansion **5.** Waste Management
Major Inconsistencies to Overcome	Difference in system boundaries: MFA ↔ carbon flow accounting Difference in weighing flows: In *material flow framework*: According to weight ↔ In *carbon flow framework*: According to carbon.
Major Data Limitations	Consumption and waste: Sufficiently reliable data on the national level are not available. MFA: MFA specifies only rough categories of domestic outflows to water, air and land.
Bridge to ACBM II	On the aggregation level of PROD and CONSU/WASTE. As a consequence of grasping production, consumption and waste (including waste management) on the level of MFA, system boundaries are drawn differently in the ACDb compared to the ACBM II. In the latter the consumption of goods is part of its production system, while in the ACDb the boundaries are drawn between production (PROD) and consumption combined with waste (CONSU/WASTE).

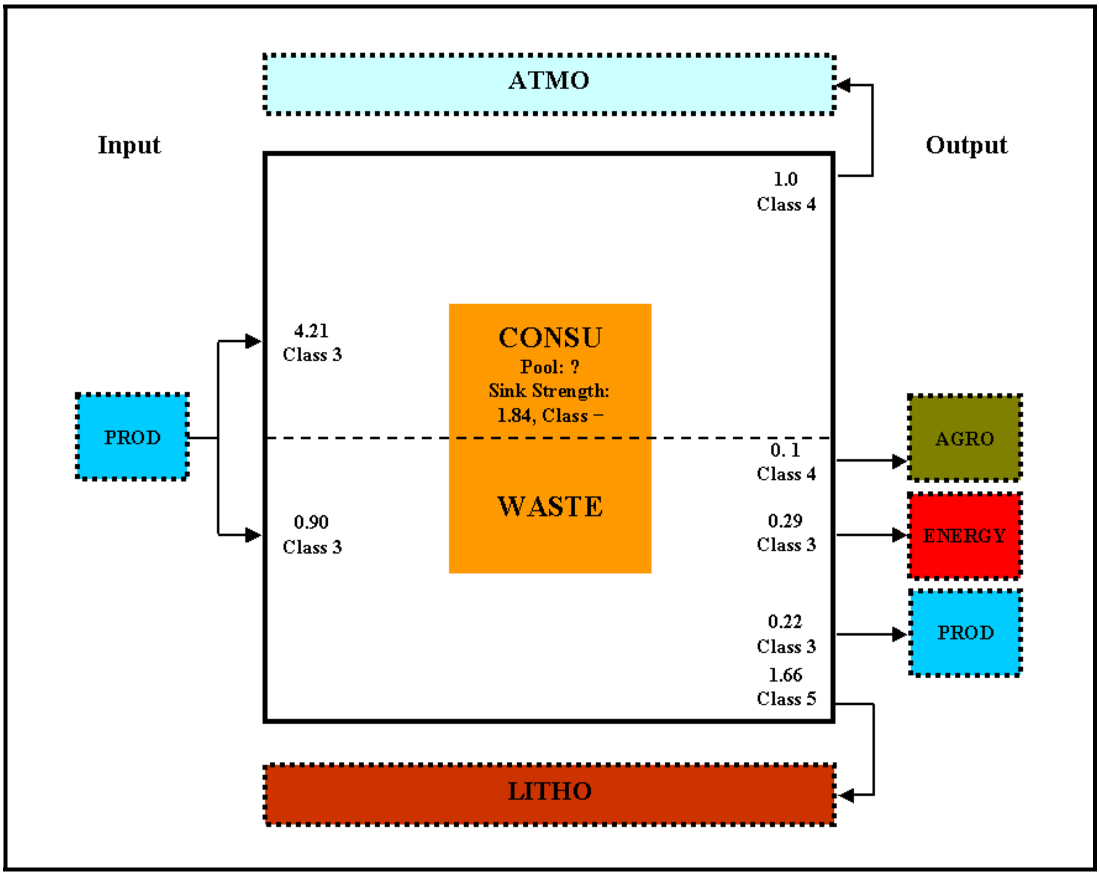

Figure 25: ACDb CONSU/WASTE module (1990): The module's setting within the ACDb. Unit of pools: 10^6 tC; unit of fluxes and pool changes: 10^6 tC yr^{-1}. Source: Kubeczko (2001a), modified.

Table 11: Basic characteristics of the ACDb AGRO module.

Module	**AGRO**				
File Name	agro.xls				
Thematic Coverage	1. Austria's LUC 2. Austria's agricultural system including soil (0–50 cm) and husbandry				
Consistency	Intra-modular consistency on the level of material flow accounting				
Integration	Linkages to other modules on the level of carbon flow accounting				
Main Data Sources	1. Statistics Austria (formerly Austrian Central Statistical Office), Austrian Forest Inventories (AFIs) 1961/70 – 1992/96, Austrian Environmental Soil Surveys (ESSs), Federal Office of Metrology and Surveying (FOMS), Jonas (1997), Schidler (1998) 2. Statistics Austria (including its ISIS database), Austria's Federal Institute of Agricultural Economics, IPCC (1997c), Schidler (1998), numerous expert contributions and specific data sources including BORIS (see ACDb)				
Temporal Coverage	1. LUC Austria: 1970–1998; LUC Provinces: 1988–1992 2. 1980–1999 or 1980–1998, respectively, if related to LUC Austria (except for soil carbon calculations and PROD→AGRO flows) Soil carbon: 1990 PROD→AGRO flows: 1990				
Temporal Resolution	Annual (1987–1993 averages are assigned to 1990, where possible)				
Thematic Resolution	1. Forests; arable land (including commercially used gardens); grassland; vineyards, orchards and gardens; other productive areas; wetlands; sealed areas; other non-productive areas 2. Grouped appropriately (calculation dependent): Cereals: 6; root and tuber crops: 3; grain legumes: 3; oil plants, fibre and commercial plants: 3; field forage growing: 2; field vegetables: 12; hay from meadows; fruit, vine and garden crops coproducts; harvest and root residues soils: 0–20 cm and 20–50 cm dairy and non-dairy cattle; pigs; sheep; goats, horses; poultry meat; milk; eggs				
Spatial Reference	Data are aggregated into a tabular form and not geo-referenced.				
Titles of Worksheets	**1.** General **2.** LUC Austria **3.** LUC Provinces **4.** Plant Prod C Conv **5.** Field Crop Prod	**6.** Fruit + Vine Prod, etc **7.** Hay Prod **8.** Harv Use **9.** Coprod +HRR C Conv **10.** Coprod Use	**11.** Non-Forest Phytomass **12.** Non-Forest NPP **13.** Synthesis Coeff **14.** Soil-Atmo Interface **15.** Non-Forest Soil C	**16.** Livest Prod C Conv **17.** Livest Prod **18.** Cattle C Balance **19.** Pig C Balance **20.** Other Livest C Balance	**21.** Livest Feed Intake **22.** Livest C Emis **23.** Livest Degrad C **24.** C to Energy **25.** Bridge to ACBM II
Major Inconsistencies to Overcome	Areal inconsistencies For instance: LUC classes ↔ Austria's total area; agricultural areas (dependent on thematic resolution) ↔ respective LUC classes				
Major Data Limitations	Measurements of above and belowground phytomass as well as NPP: Systematic measurements particularly for all types of grassland, other productive areas, orchards, vineyards and gardens are not available. Soil: So far, only a few ESSs were repeated systematically on the provincial level. Soil respiration: Systematic measurements to determine the emissions or removals of CO_2 and other relevant GHGs by Austria's non-forest soils in consideration of LUC are not available. Carbon conversion: Derived factors are not exclusively specific for Austria.				
Bridge to ACBM II	Provided (see Worksheet 25)				
Support File(s)	ipcc cattle+pig.xls				

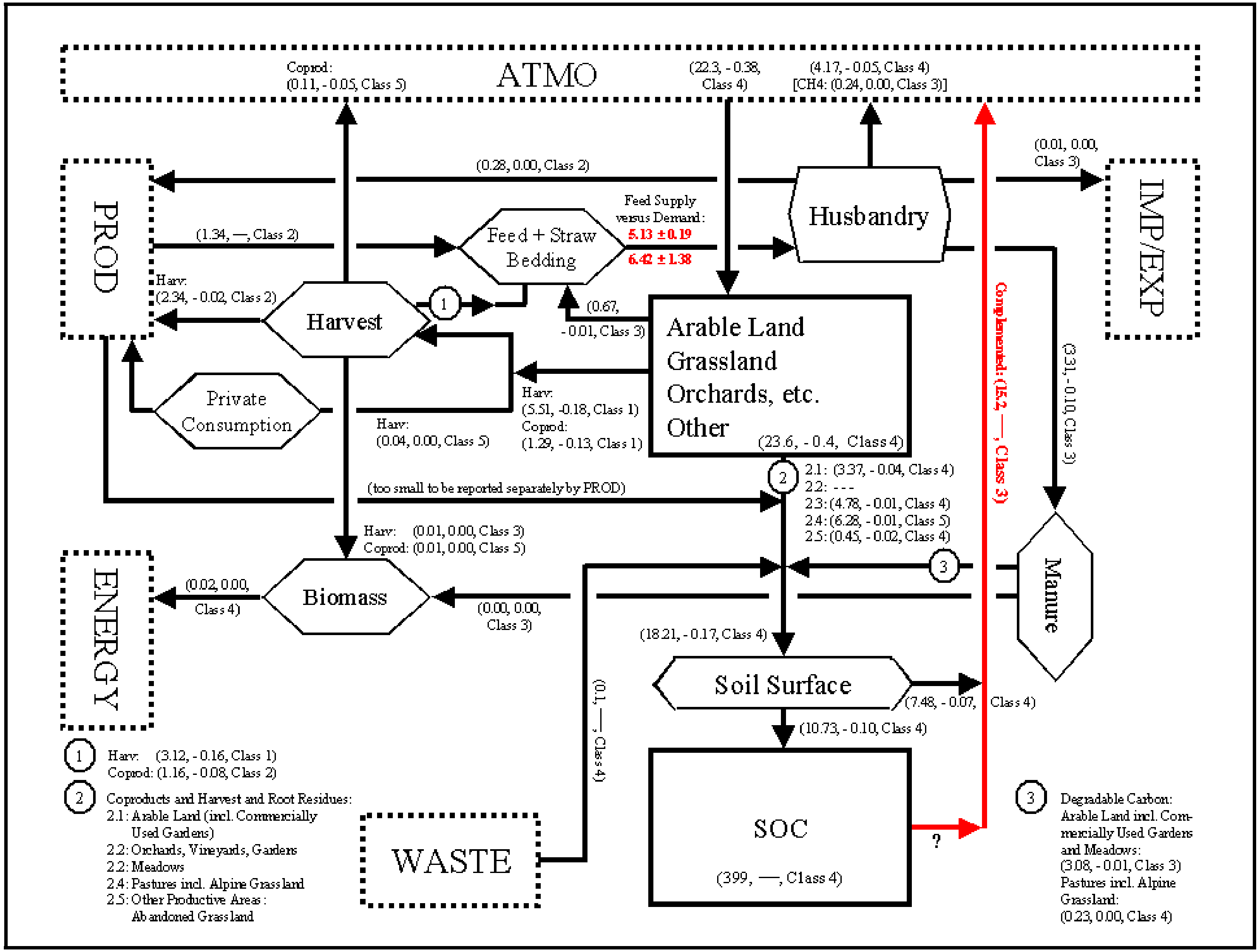

Figure 26: ACDb AGRO module: 1990 pools and fluxes, each of them characterized by two numbers and an uncertainty specification: 1990 mean, 1990 trend, and the relative uncertainty class underlying the 1990 mean. See Table 12 for units.

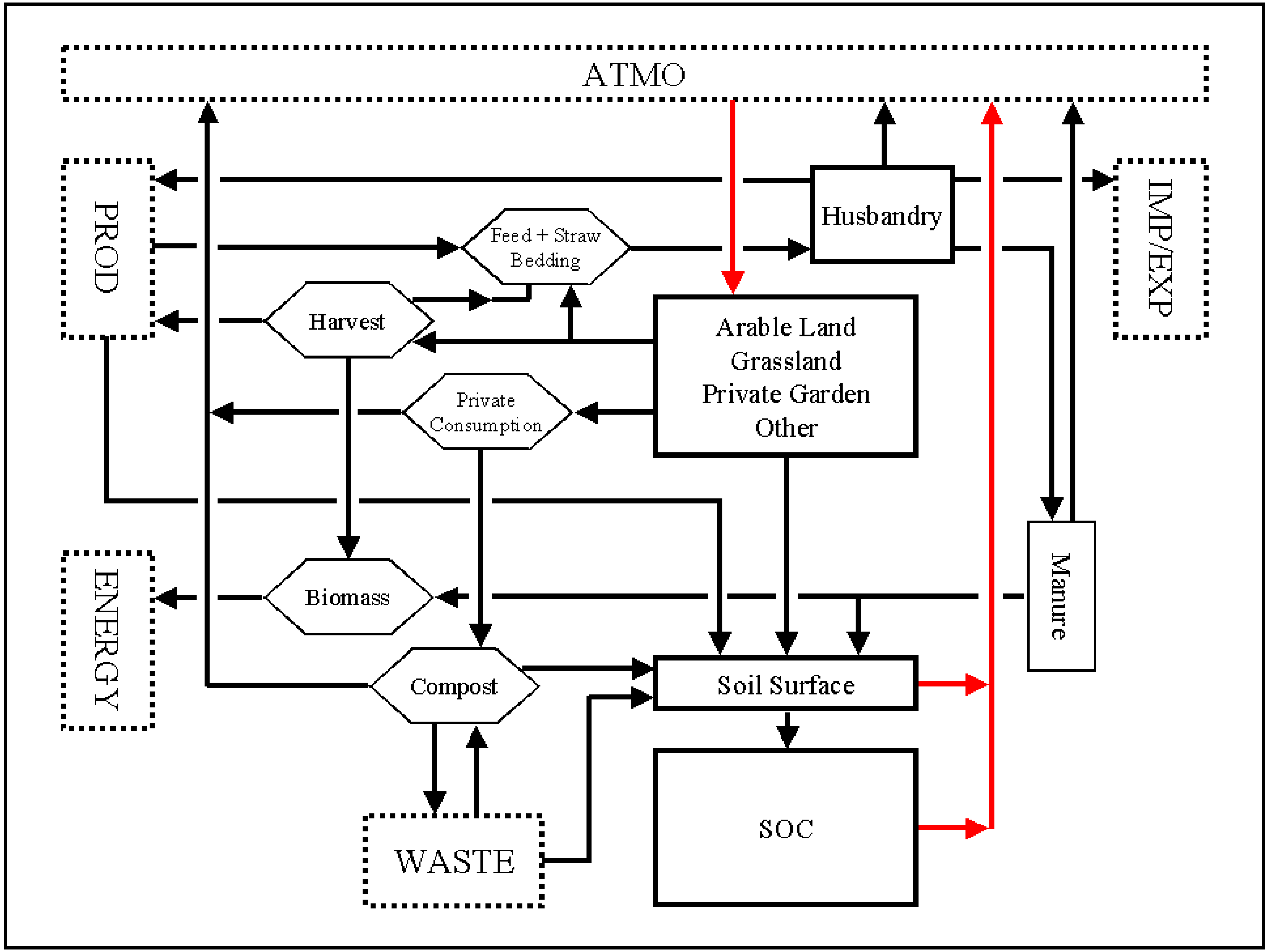

Figure 27: The ACBM II AGRO module (modified).

Table 12: Table to Figure 26. For the complemented data see text.

Available Data					
Pool			**1990 Mean 10^6 tC**	**1990 Trend 10^6 tC / yr**	**Uncertainty**
Non-Forest Biomass			23.6	- 0.4	Class 4
Non-Forest Soil			399	---	Class 4
Flux	**Origin**	**Destination**	**1990 Mean 10^6 tC yr^{-1}**	**1990 Trend 10^6 tC yr^{-1} / yr**	**Uncertainty**
Net Primary Production:					
Net Primary Production	Atmosphere	Arable Land Grassland Orchards, etc. Other	22.3	- 0.38	Class 4
Harvest (excluding Coproducts):					
Harvest: Arable Land (including Commercially Used Gardens), Orchards, Vineyards, Gardens and Meadows	Arable Land Grassland Orchards, etc. Other	Harvest Private Consumption	5.51	- 0.18	Class 1
Harvest: Gardens	Arable Land Grassland Orchards, etc. Other	Private Consumption	0.04	0.00	Class 5
Harvest to ENERGY	Harvest	Biomass	0.01	0.00	Class 3
Harvest to Husbandry	Harvest	Feed + Straw Bedding	3.12	- 0.16	Class 1
Harvest to PROD	Harvest	PROD	2.34	- 0.02	Class 2
Harvested Coproducts:					
Coproducts (Straw, Fodder Beet Foliage): Arable Land	Arable Land Grassland Orchards, etc. Other	Harvest	1.29	- 0.13	Class 1
Coproducts to ATMO	Harvest	ATMO	0.11	- 0.05	Class 5
Coproducts to ENERGY	Harvest	Biomass	0.01	0.00	Class 5
Coproducts to Husbandry	Harvest	Feed + Straw Bedding	1.16	- 0.08	Class 2

Table 12: Continued.

Flux	Origin	Destination	1990 Mean 10^6 tC yr^{-1}	1990 Trend 10^6 tC yr^{-1} / yr	Uncertainty
Available Data					
Soil Surface:					
Total Fresh Organic Matter (Coproducts Left On-site, Harvest and Root Residues, Manure, Re-used Waste) to Soil Surface	Arable Land Grassland Orchards, etc. Other Manure Waste	Soil Surface	18.21	- 0.17	Class 4
Total Fresh Organic Matter to Soil (Decomposition)	Soil Surface	SOC	10.73	- 0.10	Class 4
Total Fresh Organic Matter to ATMO (Decomposition)	Soil Surface	ATMO	7.48	- 0.07	Class 4
Soil Organic Carbon (SOC):					
Total Fresh Organic Matter to Soil (Potential Flux)	Soil Surface	SOC	10.73	- 0.10	Class 4
Not Available — Complemented: **Heterotrophic Respiration**	Soil Surface SOC	ATMO	15.2	---	Class 3
Husbandry:					
Harvest to Husbandry	Feed + Straw Bedding	Husbandry	3.12	- 0.16	Class 1
Coproducts (Straw, Fodder Beet Foliage) to Husbandry	Feed + Straw Bedding	Husbandry	1.16	- 0.08	Class 2
Farm Feed: Milk	Husbandry	Husbandry	0.03	0.00	Class 3
Feed: Pastures	Arable Land Grassland Orchards, etc. Other	Husbandry	0.67	- 0.01	Class 3
Feed: PROD	PROD	Husbandry	1.34	---	Class 2
Total Feed Supply (1990):			**5.13 ± 0.19**		**Class 1**
Livestock Products	Husbandry	PROD	0.28	0.00	Class 2
Import/Export of Livestock Products	Husbandry	IMP/EXP	0.01	0.00	Class 3
Total Emissions: Respiration, Enteric Fermentation, Manure Management	Husbandry	ATMO	4.17	- 0. 05	Class 4
Total Degradable Carbon (Excretion, Straw)	Husbandry	Manure	3.31	- 0.10	Class 3
Total Feed Demand (1987–1983) According to IPCC (1997a, b, c):			**6.42 ± 1.38**		**Class 4**

Table 12: Continued.

Flux	Origin	Destination	1990 Mean 10^6 tC yr^{-1}	1990 Trend 10^6 tC yr^{-1} / yr	Uncertainty
Available Data					
Manure:					
Total Degradable Carbon (Excretion, Straw)	Husbandry	Manure	3.31	- 0.10	Class 3
Degradable Carbon (Excretion, Straw) to Arable Land including Commercially Used Gardens	Manure	Soil Surface	3.08	- 0.01	Class 3
Degradable Carbon (Excretion) to Pastures including Alpine Grassland	Manure	Soil Surface	0.23	0.00	Class 4
Degradable Carbon (Excretion, Straw) for Biogas	Manure	Biomass	0.00	0.00	Class 4
Biomass:					
Harvest to ENERGY	Harvest	Biomass	0.01	0.00	Class 3
Coproducts to ENERGY	Harvest	Biomass	0.01	0.00	Class 5
Degradable Carbon (Excretion, Straw) for Biogas	Manure	Biomass	0.00	0.00	Class 4
Total Carbon to ENERGY	Biomass	ENERGY	0.02	0.00	Class 4
Complemented Data					
Flux	**Origin**	**Destination**	**1990 Mean 10^6 tC yr^{-1}**	**1990 Trend 10^6 tC yr^{-1} / yr**	**Uncertainty**
Heterotrophic Respiration	Soil Surface SOC	ATMO	15.2	---	Class 3

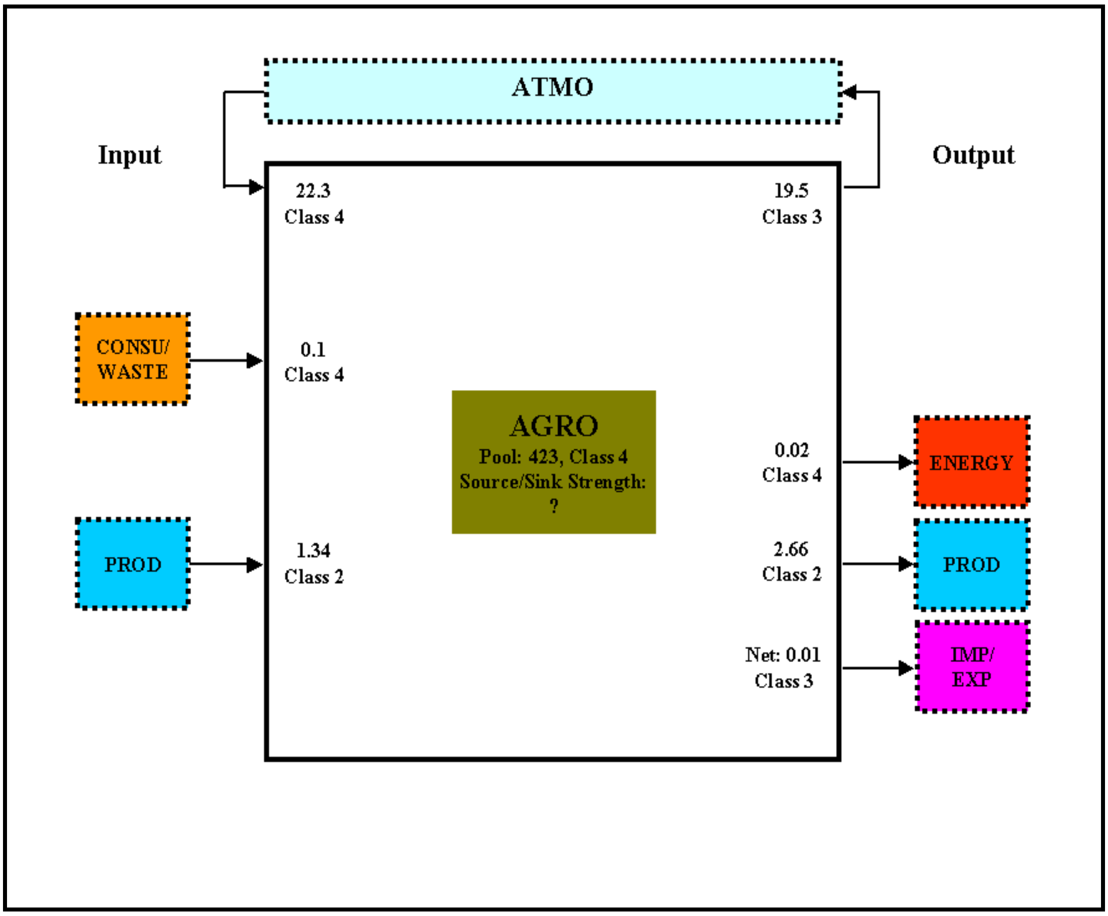

Figure 28: ACDb AGRO module (1990): The module's setting within the ACDb, which is derived by aggregating Figure 26. Unit of pools: 10^6 tC; unit of fluxes and pool changes: 10^6 tC yr^{-1}.

Like FORESTRY, several data limitations exist that prevent the complete realization of the AGRO module solely based on measured data. The first — no knowledge on changes in soil carbon — reflects the fact that, so far, only a few Environmental Soil Surveys (ESSs) were repeated systematically on the provincial level. The second — inadequate knowledge on soil respiration — is due to the fact that systematic measurements are unavailable, which is why we specify soil respiration (15.2 tC yr^{-1}; relative uncertainty class 3), by way of exception, with the help of three model results.[49] Our estimates of NPP should not obscure the fact that systematic measurements of this quantity are also urgently needed.

Husbandry provides an excellent indication on the quality of our inter- as well as intra-modular coupling. For instance, the feed supply for Husbandry amounts to (5.13 ± 0.19)

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[49] Jonas (1997) derives 18.2 10^6 tC yr^{-1} using the ACBM I, while Orthofer *et al.* (2000) find 12.4 10^6 tC yr^{-1} using the ACBM II. In addition, we construct a third *result* by considering our emissions due to decomposition (7.5 10^6 tC yr^{-1}; see Figure 26) plus heterotrophic respiration excluding decomposition (7.5 10^6 tC yr^{-1}), as provided by the ACBM II. We suspect that the relative uncertainty class 3, which we derive with the help of these three values, is too accurate (small) by one class.

10^6 tC yr^{-1}, while its feed demand amounts to (6.42 ± 1.38) 10^6 tC yr^{-1} (see Figure 26 and Table 12). We did not reconcile the overlapping uncertainty ranges of these two fluxes by applying the IIASA uncertainty concept, because this would require the recalculation of many fluxes out of Husbandry, particularly directed towards Manure. Also, we suspect that the feed demand is too large, which we derived by following the Revised 1996 IPCC GHG Guidelines (IPCC, 1997a, b, c). They are applicable to *high performance* husbandry conditions (e.g., North American) rather than Austrian conditions. For the future, we suggest applying Austria's recent feed balance (Hohenecker, 2000), which seems to be more promising than correcting the IPCC calculational procedure. Unfortunately, we became aware of this feed balance too late in order to consider it in our Study.[50]

Figure 28 indicates that AGRO, on the whole, acts as a sink (the sum of inflows is greater than the sum of outflows). However, this conclusion would be too hasty. First, uncertainties — in particular those related to soil and biomass — are too great to permit the unambiguous characterization of AGRO as a sink (or a source). Second, we do not have any knowledge of the changes in soil carbon, which may be significantly influenced by translocation processes (e.g., leaching, surface and underground run-off), which we also do not know.[51] Third, the determination of decomposition relative to the potential carbon influx to soil depends on one quantity, the synthesis coefficient that, according to our insights, needs to be based on more measurements — indicating that we may still have difficulties with grasping first statistical moments for soils.

4.2.5 ENERGY

This section summarizes our specific experiences in setting up the ENERGY module and its results. A general overview on the module's basic characteristics is given in Table 13. Its overall carbon balance is shown in Figure 29 (see also first part of Table 14).

Our work on the ENERGY module benefited considerably from the recent study by Winiwarter and Orthofer (2000) (see also Winiwarter and Rypdal, 2001), who analyzed the uncertainties that underlie Austria's 1990 and 1997 GHG emissions inventories by applying a Monte-Carlo technique.[52] This study being available, we aimed at achieving two things: (1) comparability between three different GHG accounting schemes, which include: FCA as in the ACDb, PCA following the Revised 1996 IPCC GHG Guidelines (IPCC, 1997a, b, c), and the latter but adjusted for FCA (see Table 14); and (2) a simplified procedure for calculating uncertainties that can be directly followed step-by-step (in MS Excel) and manages without the support of a model.[53] This approach requires further discussion.

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[50] The study by Hohenecker refers to the business year 1996/97, but data can also be provided for 1989/90 (Hohenecker, 2001).
[51] Because of these irreversible carbon flows to the hydrosphere and the lithosphere, we consider the *full* carbon accounting of the terrestrial biosphere in practice as an open system.
[52] Winiwarter and Orthofer (2000) focus on CO_2, CH_4 and N_2O.
[53] Winiwarter and Orthofer (2000) applied @RISK from PALISADE Co. (NY).

Table 13: Basic characteristics of the ACDb ENERGY module.

Module	**ENERGY**
File Name	energy.xls
Thematic Coverage	1. ACDb (as well as ACBM II) consistent view: Austria's emissions related to IPCC Sector 1 (Energy), Sector 2 (Industrial Processes: Iron and steel production: Combustion and calcination),* and Sector 3 (Waste: Electrification). In addition, two more accounting schemes are considered for comparison: 2. Austria's emissions following the Revised 1996 IPCC GHG Guidelines and applying PCA as undertaken by Austria's Federal Environment Agency (FEA); 3. Austria's emissions following the Revised 1996 IPCC GHG Guidelines and applying FCA as in the ACDb. * Iron and steel production: The emissions due to the combustion and calcination are considered in ENERGY and the removal (by oxidation) of carbon in pig iron is considered in PROD.
Consistency	Intra-modular consistency on the level of material flow accounting.
Integration	Linkages to other modules on the level of carbon flow accounting (neglecting minor inconsistencies).
Main Data Sources	Austrian Air Pollutant Inventory (OLI) of Austria's Federal Environment Agency (FEA), Winiwarter and Orthofer (2000), Ritter *et al.* (2001), Winiwarter and Rypdal (2001). Additional data sources: Statistics Austria (including Alder, 1993; ISIS database), Austria's 1970–1999 energy balances of the Austrian Institute of Economic Research (AIER, 2001) and other ACDb modules.
Temporal Coverage	1990
Temporal Resolution	Annual
Thematic Resolution	Emissions/removals by sectors according to IPCC '96 and SNAP '97. CO_2, CH_4 as well as N_2O in the case of the additional accounting schemes that are considered for comparison.
Spatial Reference	Data are aggregated into a tabular form and not geo-referenced.
Titles of Worksheets	**1.** General **2.** Bio-energy, etc. **3.** Parameter Aggreg **4.** SNAP97-IPCC96 **5.** Emis + Unc [IPCC-FCA] **6.** Emis + Unc [IPCC-PCA] **7.** Bridge to ACBM II
Major Inconsistencies to Overcome	Difference between PCA and FCA.
Major Data Limitations	With respect to waste in the case of the additional accounting schemes (see also Table 10): The supply of non-hazardous waste is well covered on regional scales (with the help of regionally confined surveys); however, not yet on the national scale. The fate of the different waste fractions including their decay is not yet sufficiently understood.
Bridge to ACBM II	Provided (see Worksheet 7)
Support File(s)	oli 90_97.xls, energ balanc 90.xls

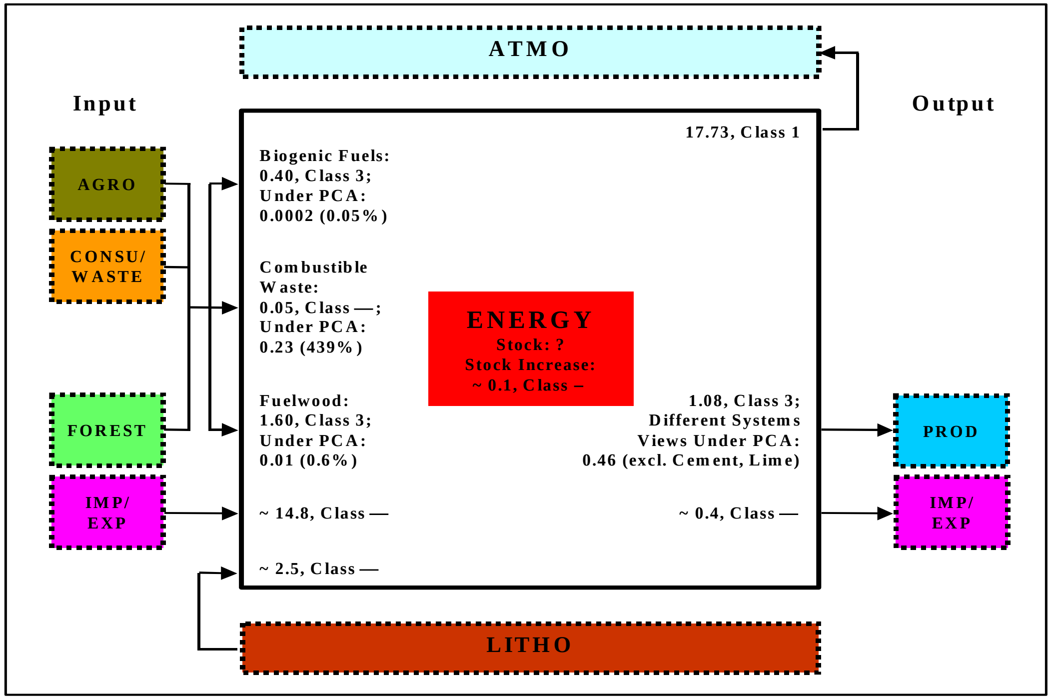

Figure 29: ACDb ENERGY module (1990): The module's setting within the ACDb. Unit of stocks: 10^6 tC; unit of fluxes and stock changes: 10^6 tC yr^{-1}.[54] The module is realized, among other things, under the condition of comparability between three different GHG accounting schemes, which include: FCA as in the ACDb, PCA following the IPCC GHG Guidelines, and the latter but adjusted for FCA. This brings about inconsistencies that occur (i) in the input linkages AGRO → ENERGY, CONSU/WASTE → ENERGY and FOREST → ENERGY[55] and the output linkage ENERGY → PROD;[56] and (ii) in the predecessor fluxes to gross domestic energy use: domestic production, import, stock changes and export. However, considering absolute flow numbers and the second order importance of the predecessor fluxes, we judge these two disadvantages negligible (see text).

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[54] In contrast to the other modules, we prefer the terms *stock* and *stock increase* to the terms *pool* and *sink strength* in the context of the ENERGY module.
[55] Under PCA, as under the IPCC GHG Guidelines, the input of, e.g., combustible waste into ENERGY is higher resolved (0.23 10^6 tC yr^{-1}) in OLI than the output from CONSU/WASTE under FCA as in the ACDb (0.05 10^6 tC yr^{-1}).
[56] The carbon input of ENERGY into PROD is subjected to different systems views under PCA as under the IPCC GHG Guidelines and FCA as in the ACDb. This difference in the systems views is in the order of 0.62 10^6 tC yr^{-1}, excluding process emissions from cement and lime production.

Table 14: Austria's 1990 energy related emissions from the IPCC source categories 1 (Energy), 2 (Industrial processes: Iron and steel production: Combustion and calcination), and 6 (Waste: Electrification). The ACDb (as well as ACBM II) consistent accounting is contrasted with an accounting according to the Revised 1996 IPCC GHG Guidelines, which is PGA based; and the same accounting but adjusted for FGA.

	CO_2 10^6 t CO_2	Unc	CH_4 10^3 t CH_4	Unc	$CO_2 + CH_4$ 10^6 t C	Unc	N_2O 10^3 t N_2O	Unc	$CO_2 + CH_4 + N_2O$ 10^6 t CO_2 eq.	Unc
FCA According to the ACDb										
Energy	57.03	Class 1	10.9	Class 3	15.56	Class 1			57.26	Class 1
Industrial Processes	7.74	Class 1	0.0	Class 4	2.11	Class 1			7.74	Class 1
Solvent and Other Product Use										
Agriculture										
Land Use Change and Forestry										
Waste	0.20	Class 3			0.05	Class 3			0.20	Class 3
Total	**64.97**	**Class 1**	**11.0**	**Class 3**	**17.73**	**Class 1**			**65.20**	**Class 1**
PGA Following the Revised 1996 IPCC GHG Guidelines										
Energy	49.69	Class 1	24.4	Class 4	13.57	Class 1	1.9	Class 3	50.79	Class 1
Industrial Processes	12.70	Class 1	0.1	Class 2	3.46	Class 1	0.6	Class 4	12.89	Class 1
Solvent and Other Product Use	0.54	Class 4			0.15	Class 4	0.8	Class 4	0.77	Class 4
Agriculture			217.4	Class 4	0.16	Class 4	3.3	Class 5	5.59	Class 5
Land Use Change and Forestry	- 9.21	Class 3			- 2.51	Class 3			- 9.21	Class 3
Waste	0.60	Class 4	295.4	Class 4	0.39	Class 4	0.0	Class 2	6.81	Class 4
Total w/o LUCF	**63.54**	**Class 1**	**537.3**	**Class 3**	**17.73**	**Class 1**	**6.6**	**Class 5**	**76.85**	**Class 1**
Total	**54.32**	**Class 1**	**537.3**	**Class 3**	**15.22**	**Class 1**	**6.6**	**Class 5**	**67.64**	**Class 2**
FGA Following the Revised 1996 IPCC GHG Guidelines										
Energy	57.03	Class 1	10.9	Class 3	15.56	Class 1	1.9	Class 3	57.85	Class 1
Industrial Processes	12.45	Class 1	0.1	Class 2	3.40	Class 1	0.6	Class 4	12.64	Class 1
Solvent and Other Product Use	0.54	Class 4			0.15	Class 4	0.8	Class 4	0.77	Class 4
Agriculture	0.05	Class 5	274.6	Class 3	0.22	Class 3	3.3	Class 5	6.84	Class 4
Land Use Change and Forestry	- 9.15	Class 5			- 2.50	Class 5			- 9.15	Class 5
Waste	0.77	Class 4	295.3	Class 4	0.43	Class 4	0.0	Class 2	6.97	Class 4
Total w/o LUCF	**70.84**	**Class 1**	**581.0**	**Class 3**	**19.76**	**Class 1**	**6.6**	**Class 5**	**85.07**	**Class 1**
Total	**61.69**	**Class 3**	**581.0**	**Class 3**	**17.26**	**Class 3**	**6.6**	**Class 5**	**75.92**	**Class 3**

The advantage of the first requirement, the comparability between PCA and FCA based accounting schemes, brings about two disadvantages: (i) Inconsistencies that occur in the input linkages of AGRO, CONSU/WASTE and FOREST with ENERGY on the one hand and the output linkage of ENERGY with PROD on the other hand (see also Figure 29). (ii) Inconsistencies that occur in the predecessor fluxes to gross domestic energy use: domestic production, import, stock changes and export. To realize the aforementioned comparability requires starting from the emissions, that is, the Austrian Air Pollutant Inventory (*Österreichische Luftschadstoff-Inventur*, OLI), which specifies Austria's emissions to the atmosphere based on Austria's gross domestic energy use and which makes use, among other sources, of official energy statistics including 1990, the year of interest here. To estimate the emissions, OLI applies a multitude of emission factors (see Ritter *et al.*, 2001), which, in turn, are laborious to follow in determining Austria's domestic production, import, stock changes and export. To circumvent this problem, considering also that these *predecessor fluxes* are of second-order importance from an emissions point of view, we approximated them with the help of a national expert (Poupa, 2001) by applying mean CO_2 conversion factors to the different energy carriers and disregarded the specification of uncertainties (which does not impair the calculation of uncertainties that underlie the fluxes to and from the atmosphere). However, considering absolute flow numbers and the second order importance of the predecessor fluxes, we judge these two disadvantages negligible.

With respect to the second requirement, we emphasize that we consider the simplified procedure for calculating uncertainties (which makes use of the law of uncertainty propagation and arising approximations) as an additional option that is more accessible to verification. However, we recommend that national emission experts realize this option after the uncertainties of national emission inventories have been assessed by applying a Monte Carlo technique in particular. We would not have carried out our simplified procedure and tested its robustness, if we would not have been safeguarded by the study of Winiwarter and Orthofer (2000).

To summarize this discussion, the two requirements enable us, for the first time, to study the national-scale effect on uncertainty of different accounting schemes that are consistent with each other, while our calculations facilitate a direct and transparent understanding of both mean values and uncertainties.

The three accounting schemes follow the structure of the 1996 IPCC source/sink categories (see also EMEP, 1999). The differences between the schemes are as follows (see Table 14):

1. *FCA as in the ACDb.* This accounting scheme is determined by the logic of the ACDb. Emissions from ENERGY are derived from OLI by taking into consideration only the energy related source categories 1 (Energy), 2 (Industrial processes: Iron and steel production: Combustion and calcination), and 3 (Waste: Electrification). The CO_2 emissions that result from the burning of biogenic fuels and fuelwood enter the accounting. The remaining emissions/removals appear — neglecting minor inconsistencies (see above) — in the other modules of the ACDb.
2. *PCA following the Revised 1996 IPCC GHG Guidelines.* This accounting scheme strictly follows the IPCC GHG Guidelines. The emissions from/removals by all six source/sink categories are considered and taken from OLI, following Austria's

official reporting procedures. It is this accounting scheme, the uncertainties of which Winiwarter and Orthofer (2000) investigated for CO_2, CH_4 and N_2O. (For a better comparison of our results with those of the authors, we carry along N_2O in our calculations.) The burning of biogenic fuels, fuelwood and peat as well as the on-site burning of straw is treated as CO_2 neutral.

3. *FCA following the Revised 1996 IPCC GHG Guidelines.* This accounting scheme also follows the IPCC GHG Guidelines but utilizes non-energy related emissions/removals from the ACDb to the extent they are specified. The remaining inconsistency that occurs in the input linkage CONSU/WASTE $\rightarrow$ ENERGY is overcome pragmatically by taking over the higher resolved OLI emissions. The CO_2 emissions that result from the burning of biogenic fuels and fuelwood as well as from the on-site burning of straw enter the accounting. (For a better comparison of these results with those of the previous accounting scheme, we carry along N_2O in our calculations.)

The comparison of the accounting schemes reveals three distinct and relevant results:

1. Our PCA as under the IPCC GHG Guidelines produces results that are in close agreement with those of Winiwarter and Orthofer (2000) and Winiwarter and Rypdal (2001) (see Table 15). The uncertainty of CO_2, as also already noted by these authors, dominates the total uncertainty, as is also the case in the other accounting schemes.
2. By way of contrast to our PCA, our FCA as under the IPCC GHG Guidelines simulates an effect, which we already anticipated in Section 3.1.2.5 (see Figure 8) and which goes back to the fact that uncertainties also add up in the case of differences of the type *emissions minus removals*. (In this PCA-FCA comparison, we can neglect how the CO_2 emissions of biogenic fuels, fuelwood, etc., are accounted, i.e., *CO_2 neutral* or not.) Reducing the total national CO_2 emissions by IPCC category 5 (LUCF: Land use change and forestry) increases their relative uncertainty (here from class 1 to 3) under FCA, but not under PCA (see Table 14: *PGA* and *FGA Following the Revised 1996 IPCC GHG Guidelines*; Lines: *Total w/o LUCF* and *Total*; Column: *Unc(CO_2)*.) This is because a (practically identical) LUCF sink strength (9.15 versus 9.21 10^6 tC yr^{-1}) with a greater relative uncertainty class (class 5 versus class 3) enters the FCA in comparison to the PCA. We recall that a greater relative uncertainty induces a greater VT.
3. Superimposing the highly uncertain emissions of the non-CO_2 GHGs with the less uncertain CO_2 emissions can also induce this aforementioned effect (see Table 14: *PGA Following the Revised 1996 IPCC GHG Guidelines*; Line: *Total*; Columns: *Unc(CO_2)* to *Unc($CO_2+CH_4+N_2O$)*.)[57] The overall emissions carry a greater relative uncertainty and thus result in a greater VT.

[57] This effect can also be observed in Table 15.

Table 15: Comparison of our PCA as under the IPCC GHG Guidelines with those of Winiwarter and Orthofer (2000) (WO in this table) and Winiwarter and Rypdal (2001) (WR in this table). Units: 10^6 t GHG eq. The emissions of each gas are reported in two lines. First line: Austria's total emissions excluding IPCC category 5. Second line: Austria's total emissions including IPCC category 5. For completeness, it is noted that WO and WR consider some natural sources (in accordance with SNAP category 11) in addition to the sinks/sources of IPCC category 5. Common reference basis: Greenhouse Warming Potentials (GWPs) (100-year time horizon) based on mass units, as requested by the Kyoto Protocol (FCCC, 1992). These are 1 for CO_2, 21 for CH_4 and 310 for N_2O (IPCC, 1996).

Unit:	**This Study See Table 14**		**Winiwarter and Orthofer (2000) [WO] Winiwarter and Rypdal (2001) [WR]**	
10^6 t GHG eq.	**Mean**	**Unc**	**Mean**	**Unc**
CO_2	63.5	Class 1	WO: 63.2 WR: 63.2	WO: Class 1 WR: Class 1
	54.3	Class 1	WO: 54.0 WR: 54.0	WO: Class 1 WR: Class 1
CH_4	11.3	Class 3	WO: 9.1 WR: 9.5	WO: Class 4 WR: Class 4
	11.3	Class 3	WO: 9.2 WR: 9.5	WO: Class 4 WR: Class 4
N_2O	2.0	Class 5	WO: 5.2 WR: 6.6	WO: Class 5 WR: Class 5
	2.0	Class 5	WO: 6.8 WR: 9.0	WO: Class 4 WR: Class 4
Total	76.85	Class 1	WO: 77.6 WR: 79.3	WO: Class 1 WR: Class 1
	67.64	Class 2	WO: 69.9 WR: 72.5	WO: Class 2 WR: Class 2

4.2.6 Synopsis

In this section we synopsize the 1990 carbon fluxes to and from all ACDb modules in the form of Table 16, similar to how Orthofer *et al.* (2000) synopsized the corresponding fluxes of the ACBM II in their Table 3-2 for 1990. However, we additionally specify these fluxes, where possible, as well as the total fluxes to and from the individual modules in terms of their uncertainties. (The latter uncertainties are only first order estimates. However, we still consider them trustworthy in conjunction with our relative uncertainty classes.) As it becomes obvious, it is the ENERGY module that reveals the smallest relative uncertainty (here: class 1). By way of contrast, the total fluxes to and from the atmosphere reveal considerably greater uncertainties (here: classes 3 and 4, respectively).

Table 16: Synopsis of all ACDb modules in terms of their (rounded) 1990 carbon fluxes and relative uncertainty classes. Unit of fluxes: 10^6 tC yr^{-1}. The relative uncertainties of the total fluxes to and from the individual modules are only first order (however, trustworthy) estimates. (Inaccuracies due to rounding: ± 0.1 10^6 tC yr^{-1}.)

TO / From	AGRO	ATMO	CONSU/ WASTE	ENERGY	FOREST	IMP/EXP	LITHO	PROD	Total
AGRO		19.5 Class 3		0.02 Class 4		Net: 0.01 Class 3		2.73[a] Class 2	**22.3 Class 3**
ATMO	22.3 Class 4				13.9 Class 5				**36.2 Class 4**
CONSU/ WASTE	0.1 Class 4	1.0 Class 4		0.29 Class 3			1.66 Class 5	0.22 Class 3	**3.3 Class 4[b,d]**
ENERGY		**17.73 Class 1**				~ 0.4 Class –		1.08 Class 3	**19.2 Class 1[c]**
FOREST		7.7 Class 5		1.73 Class 3		0.24 Class 3		4.02 Class 3	**13.7 Class 5**
IMP/EXP				~ 14.8 Class –	1.07 Class 3			2.99 Class 2	**18.9 Class 1[c]**
LITHO				~ 2.5 Class –				0.82 Class 3	**3.3 Class 1[c]**
PROD	1.34 Class 2	0.99 Class 3	5.11 Class 3		0.96 Class 3	3.49 Class 3			**11.9 Class 2**
Total	**23.7 Class 4[b]**	**46.9 Class 3[b]**	**5.1 Class 3**	**19.3 Class 1[c]**	**15.9 Class 5**	**4.1 Class 2[c]**	**1.7 Class 5**	**11.9 Class 1[b]**	**128.8 / 128.6**

[a] Arithmetic mean of 2.80 (see Figure 24) and 2.66 10^6 MtC yr^{-1} (see Figure 28).
[b] Relative uncertainties assigned to CONSU/WASTE → AGRO, CONSU/WASTE → ATMO, and CONSU/WASTE → PROD: Class mean values.
[c] Relative uncertainty assigned to IMP/EXP → ENERGY, LITHO → ENERGY, and ENERGY → IMP/EXP: 2.5% (mean of class 1).
[d] Relative uncertainty assigned to CONSU/WASTE → LITHO: 50%.

Together Austria's biospheric pools (FOREST: see Figure 23; AGRO: see Figure 28) comprise 1170 10^6 tC (class 3). With respect to its rate of change, only the sink strength of the FOREST module (2.5 10^6 tC / yr, class 5) can be specified. A source or sink strength of the AGRO module cannot yet be specified unambiguously due to too great uncertainties.

4.3 Conclusions

This section reaches conclusions of our inductive research phase, which we consider being generally valid and are not only specific for Austria. They are as follows:

- To generate a full carbon (or GHG) account for a country, which — ultimately — should be based on MFA because of its more direct link to the country's socioeconomic activities, is not an easy task. An instructional manual with clear guidelines on how to accomplish this is not available and it will take some time until this will be the case. (Compared to other countries, Austria is in a better position to achieve this goal. It belongs to a handful of countries, which have already undergone a MFA comparison and which have the entire expertise in place to base FGA appropriately on MFA in the future.) In realizing the various modules of the ACDb, we faced major data limitations and had to overcome major inconsistencies practically for all of them, a situation which we consider typical for many countries (see Tables 5, 9, 10, 11 and 13: Lines: *Major Data Limitations* and *Major Inconsistencies to Overcome*.) The first include unavailable systematic (including repeated) measurements for forest and non-forest land with respect to: NPP, soil respiration, soil carbon, belowground phytomass; for non-forest land with respect to: aboveground phytomass; sufficiently complete and reliable consumption and waste data on the national scale; etc. The latter include inconsistencies with regard to PCA versus FCA, inconsistencies related to using MFA as a basis for carbon flow accounting, inconsistencies appearing in the context of *two-sided* statistics, etc.

- We consider Austria to be a *data-rich* country. In a number of cases, even *two-sided* statistics are available. These are most interesting because they generally disagree and thus lead to deeper insights with respect to the involved subsystems and uncertainties. Typically, expert review teams that screen country data encounter *one-sided* statistics (if at all) and *two-sided* statistics only infrequently. Whenever these occur, the tendency to misinterpret such situations is pronounced by questioning the data-statistical quality standards of these countries. However, the opposite seems more likely to be true. Making *two-sided* statistics available must be highly appreciated because the expert review teams receive the rare possibility of scrutinizing the quality of their work and asking themselves what they could not adequately review if countries provided them with only *one-sided* statistics.
- We consider the established ACDb useful. It attributes special importance to the direct and transparent understanding of both mean values and uncertainties. We are confident that other experts, who use our data sets, will estimate uncertainty ranges that overlap ours. We materialize this by introducing relative uncertainty classes (see Table 4). Based on our experiences, we strongly recommend the application of such classes as a common good practice measure. They constitute a robust means to get an effective grip on uncertainties. In light of the aforementioned data limitations and inconsistencies, the reporting of exact relative uncertainties is not justified. We interpret the relative uncertainty classes qualitatively in a gradual manner ranging from (see Table 17):

  Class 1: *Fluxes and pool changes have good potential to be considered in the Kyoto policy process.*

  to

  Class 4: *Major knowledge gaps exist. Fluxes and pool changes require, in general, separate consideration from lower class fluxes and pool changes and should not be intermingled.*
- PCA, as under the Revised 1996 IPCC GHG Guidelines or the Kyoto Protocol, does not ensure that the physical law of conservation of matter is rigorously preserved in deriving biospheric sink (or source) strengths. Compliance with this physical boundary condition can lead to a greater uncertainty to be considered in the accounting. In this context, the accounting of LULUCF activities under the Kyoto Protocol is least trustworthy, revealing uncertainties potentially greater than

100%. The implications of this are essentially unexplored with respect to Articles 3.3 and 3.4 of the Protocol but may be crucial for their implementation.

- The consideration of forest (as well as other biospheric) sink strengths in the total national CO_2 emissions increases the overall relative uncertainty of the combined CO_2 emissions (potentially also in terms of classes depending on the magnitude of the sink strength). As already shown in our inductive research phase, a greater relative uncertainty induces a greater VT.
- Superimposing the highly uncertain emissions of the non-CO_2 GHGs with the less uncertain CO_2 emissions can also induce the aforementioned effect. The overall emissions carry a greater relative uncertainty and thus result in a greater VT.
- The ENERGY module reveals — as the only module of the ACDb — the smallest relative uncertainty class (the module's CO_2 emissions fall into class 1), a situation which we consider typical for many countries. Thus, in combination with the two aforementioned conclusions, this supports our request for bifurcated rules (actually, Protocols) that are needed to treat the more easily verified fluxes (FF CO_2, especially) differently from those that are more uncertain (notably, LULUCF CO_2) (see Section 3.3).
- To assess the uncertainties of national emission inventories, countries may opt for applying a stochastic analysis (the Monte Carlo technique) for scientific safeguard. However, we see the advantage of complementing (not replacing) this technique by a simplified calculational procedure, which makes use of the law of uncertainty propagation as well as arising approximations, but which is more accessible to external verification.

Table 17: Table 4 extended to include our qualitative understanding of the relative uncertainty classes.

Class	**Relative Uncertainty [%]**	**Qualitative Understanding Items in Focus: Fluxes and Pool Changes (Source/Sink Strengths)**
1	0–5	Class 1 items have good potential to be considered in the Kyoto policy process.
2	5–10	
3	10–20	
4	20–40	Major knowledge gaps exist. Class 4 items should be treated separately from class 1 items and not be intermingled. (Exception: When Class 4 items are negligible.)
5	> 40	

Part 5: Overall Conclusions and Research Challenges

5.1 Overall Conclusions

This section reaches conclusions of both our deductive and inductive research phase. We continue to focus on conclusions that are generally valid and are not only specific for Austria. To this end, we start from the conclusions of our deductive research phase (see Section 3.3), which are general *per definitionem*, and match them by the conclusions of our inductive research phase (see Section 4.3). Proceeding in this way shows that our *inductive-research-phase* conclusions methodologically complement two of our *deductive-research-phase* conclusions, which address the issue of FCA (or FGA, respectively) as the appropriate basis for accounting and the issue of bifurcated rules for treating the more easily verified fluxes differently from those that are more uncertain:

<table>
<tr><th>Part 3: Deductive Research Phase Conclusions (cf. Section 3.3):</th><th>Part 4: Inductive Research Phase Conclusions (cf. Section 4.3):</th></tr>
<tr><td colspan="2">The Kyoto Protocol and the way in which national emissions are inventoried urgently need fundamental as well as methodological improvements, more than ever before. In order to guide the Protocol towards success and improve national emission inventories, we conclude:</td></tr>
<tr><td>• A robust Full Carbon Accounting (FCA) system [embedded into a proper Full Greenhouse Gas Accounting (FGA) system], which permits the quantification of uncertainties within this wider context, is required. Only such an accounting system can form a solid basis for the Kyoto Protocol.</td><td>• The generation of a full carbon (or greenhouse gas) account for a country, which — ultimately — should be based on Material Flow Analysis (MFA) because of its more direct link to the country's socioeconomic activities, is not an easy task, but needs to be tackled. An instructional manual with clear guidelines on how to accomplish this is not available and it will take some time until this will be the case. Major data limitations and inconsistencies will occur, a situation which we consider typical for many countries.
• We recommend the application of relative uncertainty classes as a common good practice measure. They constitute a robust means to get an effective grip on uncertainties. In light of the aforementioned data limitations and inconsistencies, the reporting of exact relative uncertainties is not justified.
• To assess the uncertainties of national emission inventories, we suggest — in addition to applying Monte Carlo analysis for scientific safeguard — a simplified calculational procedure, which makes use of the law of uncertainty propagation as well as arising approximations, but which is more accessible to external verification.</td></tr>
</table>

	• Austria is a *data-rich* country, making even *two-sided* statistics available in a number of cases. These are most interesting because they generally disagree, offering to expert review teams the rare possibility of scrutinizing the quality of their work and asking themselves what they could not adequately review if countries provided them with only *one-sided* statistics. We suspect that, in the short-term, increased data richness will uncover more of such predicaments rather than confirming existing understanding. • Partial Carbon Accounting (PCA), as under the Revisied 1996 IPCC Greenhouse Gas Guidelines or the Kyoto Protocol, does not ensure that the physical law of conservation of matter is rigorously preserved in deriving biospheric sink (or source) strengths. Compliance with this physical boundary condition can lead to a greater uncertainty to be considered in the accounting. This shortcoming needs to be remedied. The accounting of biospheric sink (or source) strengths as under the Kyoto Protocol is least trustworthy, revealing uncertainties potentially greater than 100% and, thus, implications that may be crucial with respect to the implementation of Articles 3.3 and 3.4 of the Protocol.
• The biosphere must be treated as one system and must not be split into a *Kyoto* and a *non-Kyoto biosphere*.	
• The two-points-in-time IPCC uncertainty concept must be replaced by a verification concept that is sufficient in terms of temporal verification.	
• Bifurcated rules (actually, Protocols) are needed that treat the more easily verified fluxes (fossil fuel CO_2, especially) differently from those that are more uncertain (notably, CO_2 sinks).	• The consideration of forest (as well as other biospheric) sink strengths in the total national CO_2 emissions increases the overall relative uncertainty of the combined CO_2 emissions (potentially also in terms of classes depending on the magnitude of the sink strength). As shown in our inductive research phase, a greater relative uncertainty induces a greater verification time (VT), which is the time until a signal begins to outstrip its underlying uncertainty. • Superimposing the highly uncertain emissions of the non-CO_2 greenhouse gases with the less uncertain CO_2 emissions can also induce the aforementioned effect. The overall emissions carry a greater relative uncertainty and thus result in a greater VT.

	• The ENERGY module's CO_2 emissions reveal — as the only module of the ACDb — the smallest relative uncertainty class, a situation which we consider typical for many countries. In combination with the two aforementioned conclusions, this supports our request for bifurcated rules (actually, Protocols) that are needed to treat the more easily verified fluxes differently from those that are more uncertain.
• An understanding of what the environmental criteria under the Kyoto Protocol should be must be developed. Environmental objectives (e.g., sustainability criteria) need to be introduced as a *condicio sine qua non* before economic measures are permitted to take effect.	

5.2 Research Challenges

This section concludes our Study by addressing some research challenges that we see ahead of us. Most of these can be directly derived from our conclusions, namely:

- Generation of an instructional manual of how to carry out national-scale full carbon accounts (embedded into proper FGA), which also permit the quantification of uncertainties within this wider context. Only such an accounting system can form a solid basis for accounting greenhouse gas emissions and removals under the Kyoto Protocol.
- Reconciliation of FGA with national-scale MFA. This provides a more direct link between a country's FGA and its socioeconomy and helps to derive policy relevant conclusions more readily.
- Generation of a verification concept that is sufficient in terms of temporal verification. It must replace the two-points-in-time IPCC uncertainty concept.
- Generation of bifurcated rules that treat the more easily verified fluxes (fossil fuel CO_2, especially) differently from those that are more uncertain (notably, CO_2 sinks). This would considerably increase the effectiveness of the Kyoto Protocol.
- Specification of the environmental objectives (e.g., sustainability criteria) that need to be introduced (as a *condicio sine qua non*) before economic measures are permitted to take effect.

In addition, we perceive the need of assigning scientific credibility to the national-scale registry of the various emission/removal units (AAUs: Assigned Amount Units, ERUs: Emission Reduction Units, CERs: Certified Emission Reductions, RMUs: ReMoval Units) that are currently discussed in the context of the accounting modalities under the Kyoto Protocol (e.g., FCCC, 2001e; Howard, 2001; IISD, 2001b). By this we mean, in principle, the scientific (i.e., objective and independent) quantification of the verification regimes, under which the countries operate and the knowledge of which would permit quantifying the aforementioned credibility. (By way of contrast, expert review teams will work in a PCA world and under verification conditions that are not rigorous — unable to master uncontrollable situations as, e.g., described in Section 3.1.5.2.) Assigning this credibility would be similar to assigning a solvency or quality stamp as, e.g., used in rating banks. Countries will not only be interested in how the registry system under the Kyoto Protocol will eventually function, but also how verifiable their partner countries are in reducing their emissions under the Protocol or when trading emission/removal units with them. A presently ongoing IIASA study aims at quantifying the verification regimes of Annex I countries.

References

AIER (2001). Energiebilanzen 1970–1999 (Energy Balances 1970–1999). Data file made available by the Austrian Institute of Economic Research (AIER), Vienna, Austria (in German).

Alder, R. (1993). Energieaufkommen und -verwendung in der österreichischen Volkswirtschaft im Jahr 1990. Endgültige Energiebilanz 1990 (Energy Supply and Utilization in the Austrian Economy in the Year 1990. Final Energy Balance). *Statistische Nachrichten*, **10**/1993, Statistics Austria (formerly Austrian Central Statistical Office), Vienna, Austria (in German).

Battle, M., M.L. Bender, P.P. Tans, J.W.C. White, J.T. Ellis, T. Conway and R.J. Francey (2000). Global Carbon Sinks and Their Variability Inferred from Atmospheric O_2 and $\delta^{13}C$. *Science*, **287**, 2467–2470.

Bolin, B. (1998). The Kyoto Negotiations on Climate Change: A Science Perspective. *Science*, **279**, 330–331.

Canadell, J. and I. Noble (2001). Recent Advances in Terrestrial Carbon Cycle Research. *Global Change Newsletter*, **46**, June, 24–26.

Charles, D., B.M.R. Jones, A.G. Salway, H.S. Eggleston and R. Milne (1998). Treatment of Uncertainties for National Estimates of Greenhouse Gas Emissions. Report AEAT-2688-1. AEA Technology, Culham, United Kingdom. Available on the Internet: http://www.aeat.co.uk/netcen/airqual/naei/ipcc/uncertainty.

Dachuk, V. (2002). Looking Behind the Kyoto Protocol: Can Integral Transforms Provide Help in Dealing with the Verification Issue? (preliminary title). Interim Report. International Institute for Applied Systems Analysis, Laxenburg, Austria (forthcoming).

Egger-Rollig, E. (2001). Personal communication.

EMEP (1999). *EMEP/CORINAIR Atmospheric Emission Inventory Guidebook.* Cooperative Program for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe (EMEP), Technical Report 30, European Environment Agency, Copenhagen, Denmark. Available on the Internet: http://reports.eea.eu.int/EMEPCORINAIR/en.

Englisch, M. and P. Weiss (2001). Personal communication.

Falkowski, P., R.J. Scholes, E. Boyle, J. Canadell, D. Canfield, J. Elser, N. Gruber, K. Hibbard, P. Högberg, S. Linder, F.T. Mackenzie, B. Moore III, T. Pedersen, Y. Rosenthal, S. Seitzinger, V. Smetacek and W. Steffen (2000). The Global Carbon Cycle: A Test of our Knowledge of Earth as a System. *Science*, **290**, 291–296.

FCCC (1992). *United Nations Framework Convention on Climate Change.* (FCCC) Available on the Internet: http://www.unfccc.de/.

FCCC (1998). *Report of the Conference of the Parties on Its Third Session, Held at Kyoto From 1 to 11 December 1997. Addendum.* Document FCCC/CP/1997/7/Add.1. United Nations Framework Convention on Climate Change (FCCC). Available on the Internet: http://www.unfccc.de/.

FCCC (2001a). *Review of the Implementation of Commitments and of Other Provisions of the Convention. Preparations for the First Session of the Conference of the Parties Serving as the Meeting of the Parties to the Kyoto Protocol (Decision 8/CP.4).* Document FCCC/CP/2001/L.7. United Nations Framework Convention on Climate Change (FCCC). Available on the Internet: http://www.unfccc.de/.

FCCC (2001b). *Preparations for the First Session of the Conference of the Parties Serving as the Meeting of the Parties to the Kyoto Protocol (Decision 8/CP.4). Matters Relating to Land-Use, Land-Use Change and Forestry*. Document FCCC/CP/2001/L.11/Rev.1. United Nations Framework Convention on Climate Change (FCCC). Available on the Internet: http://www.unfccc.de/.

FCCC (2001c). *Implementation of the Buenos Aires Plan of Action: Adoption of the Decisions Giving Effect to the Bonn Agreements. Draft Decisions Forwarded for Elaboration, Completion and Adoption. National Systems, Adjustments and Guidelines Under Articles 5, 7 and 8 of the Kyoto Protocol.* Document FCCC/CP/2001/L.18. United Nations Framework Convention on Climate Change (FCCC). Available on the Internet: http://www.unfccc.de/.

FCCC (2001d). *Implementation of the Buenos Aires Plan of Action: Adoption of the Decisions Giving Effect to the Bonn Agreements. Draft Decisions Forwarded for Elaboration, Completion and Adoption. National Systems, Adjustments and Guidelines Under Articles 5, 7 and 8 of the Kyoto Protocol.* Document FCCC/CP/2001/L.19. United Nations Framework Convention on Climate Change (FCCC). Available on the Internet: http://www.unfccc.de/.

FCCC (2001e). *Implementation of the Buenos Aires Plan of Action: Adoption of the Decisions Giving Effect to the Bonn Agreements. Draft Decisions Forwarded for Elaboration, Completion and Adoption. Work Program on Mechanisms (Decisions 7/CP.4 and 14/CP.4).* Document FCCC/CP/2001/L.25. United Nations Framework Convention on Climate Change (FCCC). Available on the Internet: http://www.unfccc.de/.

FCCC (2001f). *Implementation of the Buenos Aires Plan of Action: Adoption of the Decisions Giving Effect to the Bonn Agreements. Draft Decisions Forwarded for Elaboration, Completion and Adoption. Land Use, Land-Use Change and Forestry.* Document FCCC/CP/2001/L.30. United Nations Framework Convention on Climate Change (FCCC). Available on the Internet: http://www.unfccc.de/.

Fehringer, R., P.H. Brunner and H. Baumann (1997). Kunststoffflüsse und Möglichkeiten der Kunststoffverwertung in Österreich (Plastic Flows and Possibilities of the Treatment of Plastics in Austria). Monograph M-080. Austrian Federal Ministry for Environment, Youth and Family Affairs, Vienna, Austria (in German).

FMAF (1998). *Austrian Forest Report 1996 (Österreichischer Waldbericht 1996).* Federal Ministry for Agriculture, Forestry, Environment and Water Management [formerly: Federal Ministry for Agriculture and Forestry (FMAF)], Vienna, Austria.

FMESC (2001). Austrian Landscape Research for a Sustainable Relationship Between Man and Nature. Information on research program made available by the Austrian Federal Ministry for Education, Science and Culture (FMESC), Vienna, Austria. Available on the Internet: http://www.klf.at/ (see also http://htdig.nextra.at/06/07/07/karolina.begusch/german/modules/gi_lf2.htm).

Gawin, R. (2002). Level and Trend Uncertainties of Kyoto Relevant Greenhouse Gases in Poland (preliminary title). Interim Report. International Institute for Applied Systems Analysis, Laxenburg, Austria (forthcoming).

Geisler, A. and M. Jonas (2001). Contribution to a Carbon Consistent Database for Austria. Interim Report IR-01-029. International Institute for Applied Systems Analysis, Laxenburg, Austria. Available on the Internet: http://www.iiasa.ac.at.

Gusti, M. and W. Jęda (2002). Carbon Management: A New Dimension of Future Carbon Research. Interim Report IR-02-006. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Hasenauer, H., R.R. Nemani, K. Schadauer and S.W. Running (1999a). Climate Variations and Tree Growth Between 1961 and 1995 in Austria. In: T. Karjalainen, H. Spiecker and O. Laroussinie (eds.) *Causes and Consequences of Accelerating Tree Growth in Europe*. EFI Proceedings 27. European Forest Institute (EFI), Joensuu, Finland, 75–86.

Hasenauer, H., R.R. Nemani, K. Schadauer and S.W. Running (1999b). Forest Growth Response to Changing Climate Between 1961 and 1995 in Austria. *Forest Ecological Management*, **122**, 209–219.

Heimann, M. (1996). Closing the Atmospheric CO_2 Budget: Inferences from New Measurements of $^{13}C/^{12}C$ and O_2/N_2 Ratios. *Global Change Newsletter*, **28**, 9–11.

Heimann, M., C. Weber, J.C. Duinker, A. Körtzinger, L. Mintrop. N. Buchmann, E.-D. Schulze, M. Hein, A. Bondeau, W. Cramer, M. Lindner and G. Esser (1999). Natürliche Senken und Quellen des atmosphärischen Kohlendioxids: Stand des Wissens und Optionen des Handelns (Natural Sinks and Sources of Atmospheric Carbon Dioxide: Status of Knowledge and Options for Action). Report No. 287. Max Planck Institute for Meteorology, Hamburg, Germany (in German).

Hohenecker, J. (2000). Futtermittelbilanz für Österreich. Berechnungsmethoden und Datengrundlagen für das Wirtschaftsjahr 1996/97 (Feed Balance for Austria. Methodology of Calculations and Data Basis for the Business Year 1996/97). University of Agricultural Sciences, Vienna, Austria (unpublished manuscript) (in German).

Hohenecker, J. (2001). Personal communication.

Howard, A. (2001). Modalities for the Accounting of Assigned Amounts Under Article 7.4 of the Kyoto Protocol. Contribution to the FCCC Workshop on Issues Related to Articles 5, 7 and 8 on the Kyoto Protocol. United Nations Framework Convention on Climate Change (FCCC). Available on the Internet: http://www.unfccc.int/sessions/workshop/010410/presentation.pdf.

Hüttler, W., H. Payer and H. Schandl (1996). Materialflussrechnung Österreich. Gesellschaftlicher Stoffwechsel und nachhaltige Entwicklung (Material Flow Analysis of Austria. Societal Metabolism and Sustainable Development). Schriftenreihe des BMUJF, Band 1/96. Austrian Federal Ministry for Environment Series, Youth and Family Affairs (BMUJF), Vienna, Austria (in German).

IGBP (1997). *The Terrestrial Biosphere and Global Change: Implications for Natural and Managed Ecosystems.* IGBP Science, No. 1, International Geosphere-Biosphere Program (IGBP), Stockholm, Sweden.

IGBP (2001). *The Carbon Challenge. An IGBP-IHDP-WCRP Joint Project.* International Geosphere-Biosphere Program (IGBP). Communications Group, CSIRO Land and Water, Canberra, Australia.

IIASA (2000a). Is the Kyoto Protocol Workable? Press Release, 25 August, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria. Available on the Internet: http://www.iiasa.ac.at/Admin/INF/PR/PR-00.8.25.html.

IIASA (2000b). Carbon Accounting and the Kyoto Protocol. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria. *Options*, Autumn, 4–6.

IISD (2001a). Report of COP-6 Part II. *Earth Negotiations Bulletin*, **12**(176), 3–12. International Institute for Sustainable Development (IISD). Available on the Internet: http://www.iisd.ca/linkages/download/pdf/enb12176e.pdf.

IISD (2001b). COP-7 Report. *Earth Negotiations Bulletin*, **12**(189), 3–14. International Institute for Sustainable Development (IISD). Available on the Internet: http://www.iisd.ca/linkages/download/pdf/enb12189e.pdf.

IPCC (1990). *Climate Change. The IPCC Scientific Assessment. Report Prepared for the Intergovernmental Panel on Climate Change (IPCC) by Working Group 1.* J.T. Houghton, G.J. Jenkins and J.J. Ephraums (eds.), Cambridge University Press, Cambridge, United Kingdom.

IPCC (1996). *Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).* J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell (eds.), Cambridge University Press, Cambridge, United Kingdom.

IPCC (1997a, b, c). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 1: Greenhouse Gas Inventory Reporting Instructions; Volume 2: Greenhouse Gas Inventory Workbook; Volume 3: Greenhouse Gas Inventory Reference Manual.* IPCC/OECD/IEA. Intergovernmental Panel on Climate Change (IPCC) Working Group I (WG I) Technical Support Unit, Bracknell, United Kingdom.

IPCC (2000a). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories.* J. Penman, D. Kruger, I. Galbally, T. Hiraishi, B. Nyenzi, S. Emmanuel, L. Buendia, R. Hoppaus, T. Martinsen, J. Meijer, K. Miwa and K. Tanabe (eds.), Intergovernmental Panel on Climate Change (IPCC) National Gas Inventories Program, Technical Support Unit, Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan.

IPCC (2000b). *Land Use, Land-Use Change, and Forestry*. Special Report of the Intergovernmental Panel on Climate Change (IPCC). R.T. Watson, I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo and D.J. Dokken (eds.), Cambridge University Press, Cambridge, United Kingdom.

ISO (1995). *Guide to the Expression of Uncertainty in Measurement.* International Organization for Standardization (ISO), Geneva, Switzerland.

Jonas, M. (1997). Systems Analytical Assessment of the Carbon Balance in Austria: Final Report Part II: Dynamical Modeling. Research Report OEFZS-A-4255 Rev. Austrian Research Center Seibersdorf, Seibersdorf, Austria (revised).

Jonas, M., S. Nilsson, A. Shvidenko, V. Stolbovoi, M. Gluck, M. Obersteiner and A. Öskog (1999a). Full Carbon Accounting and the Kyoto Protocol: A Systems-Analytical View. Interim Report IR-99-025. International Institute for Applied Systems Analysis, Laxenburg, Austria. Available on the Internet: http://www.iiasa.ac.at.

Jonas, M., S. Nilsson, M. Obersteiner, M. Gluck and Y. Ermoliev (1999b). Verification Times Underlying the Kyoto Protocol: Global Benchmark Calculations. Interim Report IR-99-062. International Institute for Applied Systems Analysis, Laxenburg, Austria. Available on the Internet: http://www.iiasa.ac.at. Also featured in: *ACCCtuell*, Newsletter of the Austrian Council on Climate Change, **4**, February 2000, 7.

Jonas, M., M. Obersteiner and S. Nilsson (2000). How to Go From Today's Kyoto Protocol to a Post-Kyoto Future that Adheres to the Principles of Full Carbon Accounting and Global-scale Verification? A Discussion Based on Greenhouse Gas Accounting, Uncertainty and Verification. Interim Report IR-00-061. International Institute for Applied Systems Analysis, Laxenburg, Austria. Available on the Internet: http://www.iiasa.ac.at.

Körner, C., B. Schilcher and S. Pelaez-Riedl (1993). Vegetation und Treibhausproblematik: Eine Beurteilung der Situation in Österreich unter besonderer Berücksichtigung der Kohlenstoff-Bilanz (Vegetation and Greenhouse Problem: Assessment of the Austrian Situation in Consideration of the Carbon Balance). In: *Bestandsaufnahme Anthropogene Klimaänderungen: Mögliche Auswirkungen auf Österreich — Mögliche Massnahmen in Österreich (Status Report Anthropogenic Climate Change: Potential Impacts on Austria — Possible Measures in Austria).* Austrian Academy of Sciences, Vienna, Austria, 6.1–6.46 (in German).

Krammer, H.J., M. Domenig, P. Dreier and D. Lassnig (1995). *Abfallaufkommen in Österreich. Materialien zum Bundes-Abfallwirtschaftsplan 1995 (Waste Generation in Austria. Contributions to the Federal Waste Management Plan 1995).* Monograph, Band 61. Austrian Federal Ministry for Environment, Vienna, Austria (in German).

Kubeczko, K. (2001a). Austrian Carbon Database: Production and Waste. Material Flow Based Carbon Accounting for 1990. Interim Report IR-01-028. International Institute for Applied Systems Analysis, Laxenburg, Austria. Available on the Internet: http://www.iiasa.ac.at.

Kubeczko, K. (2001b). Personal communication.

Loreti, C.P., S.A. Foster, J.E. Obbagy and A.D. Little (2001). *An Overview of Greenhouse Gas Emissions Verification Issues.* Report prepared for the Pew Center on Global Climate Change, Arlington, VA, USA. Available on the Internet: http://www.pewclimate.org/projects/emissions_verification.cfm.

Martin, P.H., G.-J. Nabuurs, M. Aubinet, T. Karjalainen, E.L. Vine, J. Kinsman and L.S. Heath (2001). Carbon Sinks in Temperate Forests. *Annu. Rev. Energy Environment*, **26**, 435–465.

Matthews, E., C. Amann, S. Bringezu, M. Fischer-Kowalski, W. Hüttler, R. Kleijn, Y. Moriguchi, C. Ottke, E. Rodenburg, D. Rogich, H. Schandl, H. Schütz, E. van der Voet and H. Weisz (2000). *The Weight of Nations: Material Outflows from Industrial Economies.* World Resources Institute, Washington DC, USA.

Moss, R.H. and S.H. Schneider (2000). Uncertainties in the IPCC TAR: Recommendations to lead authors for more consistent assessment and reporting. In: R. Pachauri, T. Taniguchi and K. Tanaka (eds.) *Guidance Papers on the Cross Cutting Issues of the Third Assessment Report of the IPCC.* Intergovernmental Panel on Climate Change (IPCC), c/o World Meteorological Organization, Geneva, Switzerland, 33–51.

MPI (1999). Aktueller Forschungsschwerpunkt 1999: Quellen und Senken des atmosphärischen Kohlendioxid (Actual Research Focus 1999: Sources and Sinks of Atmospheric Carbon Dioxide). Research information made available by the Max Planck Institute for Meteorology (MPI), Hamburg, Germany. Available on the Internet: http://www.mpimet.mpg.de/deutsch/forsch.html (in German).

Nabuurs, G.J., A.J. Dolman, E. Verkaik, A.P. Whitmore, W.P. Daamen. O. Oenema, P. Kabat and G.M.J. Mohren (1999). Resolving Issues on Terrestrial Biospheric Sinks in the Kyoto Protocol. Report No. 410 200 030. Dutch National Research Program on Global Air Pollution and Climate Change, Bilthoven, The Netherlands.

Nilsson, S. (2001). Forest Policy, Criteria and Indicators, and Certification. Interim Report IR-01-024. International Institute for Applied Systems Analysis, Laxenburg, Austria. Available on the Internet: http://www.iiasa.ac.at.

Nilsson, S. and W. Schopfhauser (1995). The Carbon-sequestration Potential of a Global Afforestation Program. *Climatic Change*, **30**, 267–293.

Nilsson, S., A. Shvidenko, V. Stolbovoi, M. Gluck, M. Jonas and M. Obersteiner (2000a). Full Carbon Account for Russia. Interim Report IR-00-021. International Institute for Applied Systems Analysis, Laxenburg, Austria. Available on the Internet: http://www.iiasa.ac.at. Study also featured in: *New Scientist*, **2253**, 26 August 2000, 18–19.

Nilsson, S., M. Jonas and M. Obersteiner (2000b). The Forgotten Obligations in the Kyoto Negotiations. Document made available by the International Institute for Applied Systems Analysis, Laxenburg, Austria, on the Internet: http://www.iiasa.ac.at/Research/FOR/carb_kyoto.html?sb=10.

Nilsson, S., M. Jonas, M. Obersteiner and D. Victor (2001). Verification: The Gorilla in the Struggle to Slow Global Warming. *The Forestry Chronicle*, **77**, 475–478.

Nilsson, S., M. Jonas and M. Obersteiner (2002). COP 6: A Healing Shock. *Climatic Change,* **52**: 25–28.

NIST (2001). *Uncertainty of Measurement Results.* NIST Reference on Constants, Units, and Uncertainty, National Institute of Standards and Technology (NIST), Gaithersburg, Maryland, USA. Available on the Internet: http://www.physics.nist.gov/cuu/Uncertainty/index.html.

Obersteiner, M, Y. Ermoliev, M. Gluck, M. Jonas, S. Nilsson and A. Shvidenko (2000a). Avoiding a Lemons Market by Including Uncertainty in the Kyoto Protocol — Improved Rules. Interim Report IR-00-043. International Institute for Applied Systems Analysis, Laxenburg, Austria. Available on the Internet: http://www.iiasa.ac.at.

Obersteiner, M, M. Jonas, S. Nilsson, A. Shvidenko and M. Gluck (2000b). Trading Flexibility for Predictability — Differential Emission Dynamics and the Formation of Common Carbon Markets. Interim Report IR-00-063. International Institute for Applied Systems Analysis, Laxenburg, Austria. Available on the Internet: http://www.iiasa.ac.at.

Obersteiner, M, M. Jonas, S. Nilsson, A. Shvidenko and M. Gluck (2000c). If You Act Locally and Compute Globally: What is the Optimal Comprehensiveness of the Reference Carbon System? Interim Report IR-00-065. International Institute for Applied Systems Analysis, Laxenburg, Austria. Available on the Internet: http://www.iiasa.ac.at.

Obersteiner, M., E. Rametsteiner and S. Nilsson (2001). Cap Management for LULUCF Options: An Economic Mechanism Design to Preserve the Environmental and Social Integrity of Forest Related LULUCF Activities Under the Kyoto Protocol. Interim Report IR-01-011. International Institute for Applied Systems Analysis, Laxenburg, Austria. Available on the Internet: http://www.iiasa.ac.at.

Orthofer, R. (1997). Systems Analytical Assessment of the Carbon Balance in Austria: Final Report Part I: Carbon Balance for 1990. Research Report OEFZS-A-4195. Austrian Research Centers Seibersdorf, Seibersdorf, Austria.

Orthofer, R., E. Gebetsroither, F. Strebl, H. Schwaiger, B. Schlamadinger, G. Jungmaier, J. Spitzer, L. Canella, G. Hintermeier, A. Windsperger and F. Schneider (2000). The Austrian Carbon Balance Model (ACBM). Final Project Report OEFZS-S-0107. Austrian Research Centers Seibersdorf, Seibersdorf, Austria.

Payer, H., W. Hüttler and H. Schandl (1998). *Material Flow Accounting 1998 — Implementierung der nationalen Materialflussrechnung in das System der amtlichen Umweltberichterstattung (Material Flow Accounting 1998 — Implementation of the National Material Flow Accounting into the Official Environmental Reporting).* Institute for Interdisciplinary Studies of Austrian Universities, Department of Social Ecology, Vienna, Austria; on behalf of the Austrian Federal Ministry for the Environment, Youth and Family Affairs (in German).

Pedersen, T. (2000). Climate Change Fore and Aft: Where on Earth Are We Going? *Global Change Newsletter*, **44**, 3–4.

Pew (2001). Climate Talks in Marrakech — COP 7: Update. 9 November — Final Analysis. Information made available by the Pew Center on Global Climate Change, Arlington, VA, USA, on the Internet: http://www.pewclimate.org/cop7/statement.cfm.

Post, W.M., R.C. Izaurralde, L.K. Mann and N. Bliss (2001). Monitoring and Verifying Changes of Organic Carbon in Soil. *Climatic Change*, **51**, 77–99.

Poupa, S. (2001). Personal communication.

Ritter, M., B. Bichler, J. Brunner, M. Gangl, G. Lichtblau, S. Poupa, K. Radunsky, I. Szednyj, E. Aitz and P. Weiss (2001). Austria's National Inventory Report 2001. Submission to the United Nations Framework Convention on Climate Change 2001. Report BE-190. Federal Environment Agency, Vienna, Austria.

Rotmans, J. and M.B.A. van Asselt (2001). Uncertainty in Integrated Modeling: A Labyrinthic Path. *Integrated Assessment*, **2**, 43–55.

Rypdal, K. and L.-C. Zhang (2000). Uncertainties in the Norwegian Greenhouse Gas Emission Inventory. Report 2000/13. Statistics Norway, Oslo, Norway.

Schandl, H. (1998). *Materialfluss Österreich: Die materielle Basis der österreichischen Gesellschaft im Zeitraum 1960 bis 1995 (Material Flow Austria: The Material Basis of Austria's Society During the Period 1960–1995).* Report 50. Institute for Interdisciplinary Studies of Austrian Universities, Department of Social Ecology, Vienna, Austria (in German).

Schidler, S. (1998). *Beitrag zur Modellierung des Kohlenstoffkreislaufs für Österreich: Datengrundlage und Analyse des Modells der natürlichen Systeme (Contribution to the Modeling of Austria's Carbon Cycle: Basic Data and Model Analysis of the Natural Systems).* Diploma Thesis. University of Vienna and Vienna University of Technology, Vienna, Austria.

Schopfhauser, W. (1999). Personal communication.

Schulze, E.-D., C. Wirth and M. Heimann (2000). Managing Forests after Kyoto. *Science*, **289**, 2058–2059.

Shvidenko, A. (2001). Personal communication.

Shvidenko, A. and S. Nilsson (2001). Impact of Russian Forest on the Global Carbon Budget for 1961–1998: A Synthesis. In: *Sixth International Carbon Dioxide Conference. Extended Abstracts II.* Organizing Committee of Sixth International Carbon Dioxide Conference, Center for Atmospheric and Oceanic Studies, Tohoku University, Sendai, Japan.

Shvidenko, A.Z., S. Nilsson, V.A. Rojkov and V. Strakhov (1996). Carbon Budget of the Russian Boreal Forests: A Systems Analysis Approach to Uncertainty. In: M.J. Apps and D.T. Price (eds.) *Forest Ecosystems, Forest Management and the Global Carbon Cycle*. NATO ASI Series, Series I, Vol. 40, Springer-Verlag, Heidelberg, Germany, 145–162.

Smith, S. (2001). Verifying Sinks Under the Kyoto Protocol. Verification Research, Training and Information Center (VERTIC), Briefing Paper 01/03. Available on the Internet: http://www.vertic.org/briefing/no0103.html.

Steffen, W., I. Noble, J. Canadell, M. Apps, E.-D. Schulze, P.G. Jarvis, D. Baldocchi, P. Ciais, W. Cramer, J. Ehleringer, G. Farquhar, C.B. Field, A. Ghazi, R. Gifford, M. Heimann, R. Houghton, P. Kabat, C. Körner, E. Lambin, S. Linder, H.A. Mooney, D. Murdiyarso, W.M. Post, I.C. Prentice, M.R. Raupach, D.S. Schimel, A. Shvidenko and R. Valentini (1998). The Terrestrial Carbon Cycle: Implications for the Kyoto Protocol. *Science*, **280**, 1393–1394.

Steurer, A. (1992). Stoffstrombilanz Österreich 1988 (Substance Flow Balance Austria 1988). Schriftenreihe Soziale Ökologie, 26. Institute for Interdisciplinary Studies of Austrian Universities, Department of Social Ecology, Vienna, Austria (in German).

Steurer, A. (1994). Stoffstrombilanz 1970–1990 (Substance Flow Balance 1970–1990). Schriftenreihe Soziale Ökologie, 34. Institute for Interdisciplinary Studies of Austrian Universities, Department of Social Ecology, Vienna, Austria (in German).

Tans, P.P. and D.W.R. Wallace (1999). Carbon Cycle Research after Kyoto. *Tellus*, **51B**, 562–571.

Taylor, B.N. and C.E. Kuyatt (1994). Guideline for Evaluating and Expressing the Uncertainty of NIST Measurement Results. NIST Technical Note 1297. National Institute of Standards and Technology (NIST), Gaithersburg, Maryland, USA.

van Amstel, A.R., J.G.J. Olivier and P.G. Ruyssenaars (eds.) (2000). Monitoring of Greenhouse Gases in the Netherlands: Uncertainties and Priorities for Improvement. Report 773201 003. National Institute of Public Health and the Environment, Bilthoven, The Netherlands.

WBGU (1998). The Accounting of Biological Sinks and Sources Under the Kyoto Protocol: A Step Forwards or Backwards for Global Environmental Protection? Special Report 1998. German Advisory Council on Global Change (WBGU), Bremerhaven, Germany.

Weiss, P. (2001). Personal communication.

Weiss, P., K. Schieler, K. Schadauer, K. Radunsky and M. Englisch (2000). *Die Kohlenstoffbilanz des österreichischen Waldes und Betrachtungen zum Kyoto-Protokoll (The Carbon Balance of Austria's Forest and Considerations to the Kyoto Protocol).* Monograph M-106. Federal Environment Agency, Vienna, Austria (in German).

Winiwarter, W. and R. Orthofer (2000). Unsicherheit der Emissionsinventur für Treibhausgase in Österreich (Uncertainty of Austria's Greenhouse Gas Emissions Inventory). Final Report OEFZS-S-0072. Austrian Research Centers Seibersdorf, Seibersdorf, Austria, commissioned by Austria's Federal Environment Agency (in German).

Winiwarter, W. and K. Rypdal (2001). Assessing the Uncertainty Associated with National Greenhouse Gas Emission Inventories: A Case Study for Austria. *Atmospheric Environment*, **35**, 5425–5440.

Zechmeister-Boltenstern, S. (2001). Personal communication.

Acronyms and Nomenclature

AAU	Assigned Amount Unit
ACBM	Austrian Carbon Balance Model
ACDb	Austrian Carbon Database
AFI	Austrian Forest Inventory *(Österreichische Forst-/Waldinventur)*
AFSI	Austrian Forest Soil Inventory
Aggreg	Aggregation
AGRO	Acronym used for the agricultural module
AIER	Austrian Institute of Economic Research
ARCS	Austrian Research Centers Seibersdorf
ARD	Afforestation, Reforestation, and Deforestation
Atmo	Atmosphere
ATMO	Acronym used for the atmosphere (module)
AWB	Austrian Wood Balance *(Österreichische Holzbilanz)*
BaU	Business-as-Usual
BORIS	Soil — computer based information system *(Boden — Rechnergestütztes InformationsSystem)*
C	Carbon
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
Chem	Chemical
Consu	Consumption
CONSU/WASTE	Acronym used for the consumption/waste module
Coeff	Coefficient
Conv	Conversion
COP	Conference of the Parties
Coprod	Coproduct(s)
DC	Data Consistency
DBH	Diameter at Breast Height
Degrad	Degradable
Emis	Emissions
ENERGY	Acronym used for the energy module
ERU	Emission Reduction Unit
ESS	Environmental Soil Survey
ET	Emissions Trading
Exp	Export
FCA	Full Carbon Accounting
FEA	Federal Environment Agency Ltd., Austria
FF	Fossil Fuels
FFRC	Federal Forest Research Centre
FGA	Full Greenhouse Gas Accounting
FIAE	Federal Institute of Agricultural Economics
FOM	Fresh (primary) Organic Matter
FOMS	Federal Office of Metrology and Surveying

FOREST	Acronym used for the forestry module
GHG	Greenhouse Gas
GWP	Greenhouse Warming Potential
Harv	Harvest
HRR	Harvest and Root Residues
IIE	Institute for Industrial Ecology
Imp	Import
IPCC	Intergovernmental Panel on Climate Change
ISIS	Integrated Statistical Information System *(Integriertes Statistisches Informationssystem)*
ISO	International Organization for Standardization
JI	Joint Implementation
JRG	Joanneum Research Graz
KRT	Kyoto Reduction Target
LITHO	Acronym used for the lithosphere (module)
Livest	Livestock
LUC	Land-Use and Cover
LUCF	Land Use Change and Forestry (1996 IPCC source/sink category 5); or used as a shorter form for LULUCF (in Section 3.1.2.5 and Figure 12)
LULUCF	Land Use, Land-Use Change, and Forestry
M	Modeling
MFA	Material Flow Analysis
NCR	National Climate Report
NIST	National Institute of Standards and Technology
NPP	Net Primary Production
OLI	Austrian Air Pollutant Inventory *(Österreichische Luftschadstoff-Inventur)*
PCA	Partial Carbon Accounting
PGA	Partial Greenhouse Gas Accounting
Proc	Processing
Prod	Production
PROD	Acronym used for the production module
RMU	Removal Unit
S	Sensitivity
SNAP	Selected Nomenclature for sources of Air Pollution
SOC	Soil Organic Carbon
U, Unc	Uncertainty
Veg	Vegetation
VT	Verification Time
dm	dry matter
o.b.	over bark

ISO Country Code

AT	Austria
AU	Australia
BE	Belgium
BG	Bulgaria
CA	Canada
CH	Switzerland
CZ	Czech Republic
DE	Germany
DK	Denmark
EC	European Community
EE	Estonia
ES	Spain
FI	Finland
FR	France
GR	Greece
HR	Croatia
HU	Hungary
IE	Ireland
IS	Iceland
IT	Italy
JP	Japan
LI	Liechtenstein
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SE	Sweden
SI	Slovenia
SK	Slovak Republic
UA	Ukraine
UK	United Kingdom
US	United States

List of Contacted Scientists and Experts

See the technical report.

Appendix 1: Modular Overview of the ACDb

A-1.1 Forest Module

Worksheet	Title		Contents
General	**Database for Assessment of the Austrian Carbon Balance (ACDb): FOREST**		Information header
AWB-AFI Consistency	**AWB–AFI (Austrian Wood Balance — Austrian Forest Inventory) Consistency**		Harvest of wood: Exploitation according to Austria's Forest Inventory (AFI) and domestic supply from forest floor according to Austria's Wood Balance (AWB) are made consistent, making use of IIASA's uncertainty concept (Nilsson *et al.*, 2000a). The resulting consistency adjustment is broken down into individual adjustments for fuelwood and industrial roundwood.
	I	Consistency Adjustment — Austria's Wood Balance (AWB) *(Holzbilanz)* and Austria's Forest Inventory (AFI) *(Österr. Forst-/Waldinventur)*	
	Step 1	Consistency Adjustment of AWB and AFI in (m^3 u.b. yr^{-1})	
	Step 2	Assigning an Individual Adjustment to Domestic Fuelwood (from Forest Floor) in (m^3 u.b. yr^{-1})	
	Step 3	Assigning an Individual Adjustment to Domestic (Industrial) Roundwood (from Forest Floor) in (m^3 u.b. yr^{-1})	
	Step 4	Consistency Check	
C Conversion + Expansion	**Carbon Conversion and Extended Expansion Factors**		The uncertainties underlying the carbon conversion factor and the expansion factor are determined. The derivation of these factors is based upon the carbon content that reflects the standing stock. (and not upon the carbon that reflects net growth and exploitation or domestic supply, respectively).
	I	Preparing the Basis — Data with Reference to Standing Stock	
	Step 1	Basic Data with Reference to Standing Stock Following Körner *et al.* (1993)	
	II	From (m^3 o.b.) (stem wood, original moisture content) to (tC) (stem wood)	
	Step 1	Data for the Conversion from (m^3 o.b.) (stem wood, original moisture content) to (t dm) (stem wood)	
	Step 2	Data for the Conversion from (t dm) (stem wood) to (tC) (stem wood)	
	Step 3	Conversion from (m^3 o.b.) (stem wood, original moisture content) to (tC) (stem wood) — In Consideration of Uncertainties	
	III	From (m^3 o.b.) (stem wood, original moisture content) to (tC) (total tree biomass)	
	Step 1	Expansion Factor for the Conversion from (tC) (stem wood) to (tC) (total tree biomass)	
	Step 2	Conversion from (m^3 o.b.) (stem wood, original moisture content) to (tC) (total tree biomass) — In Consideration of Uncertainties	

Worksheet		Title	Contents
Austria's Wood Balance	**Austria's Wood Balance in Carbon Units, In Consideration of Uncertainty**		Supply and utilization of Austria's Wood Balance (AWB) are converted from [m^3 u.b. yr^{-1}] to [tC yr^{-1}]. A consistency check is carried out with respect to the uncertainty that underlies bark in the AWB.
	I	Wood Supply *(Holzaufkommen)*	
	Step 1	Basic Data in (m^3 yr^{-1}) (original moisture content)	
	Step 2	Basic Data (Level-I Summary) in (m^3 yr^{-1}) — In Consideration of AWB-AFI Consistency and Bark Adjustments and Uncertainties	
	Step 3	Conversion from (m^3 yr^{-1}) to (tC yr^{-1}) — Preserving I/Step 2 Adjustments and Uncertainties	
	II	Wood Utilization *(Holzverwendung)*	
	Step 1	Basic Data in (m^3 yr^{-1}) (original moisture content)	
	Step 2	Basic Data (Level-I Summary) in (m^3 yr^{-1}) — In Consideration of AWB-AFI Consistency and Bark Adjustments and Uncertainties	
	Step 3	Conversion from (m^3 yr^{-1}) to (tC yr^{-1}) — Preserving II/Step 2 Adjustments and Uncertainties	
	III	Uncertainty Consistency Check for Bark	
	Step 1	Consistency of the AWB Uncertainty Underlying Bark	
Veg + Soil Pools	**Vegetation and Soil Carbon Pools with Reference to Austria's Exploitable Forest**		The vegetation pool and soil carbon pool (0–50 cm) of Austria's exploitable forest are determined, thereby making use of IIASA's uncertainty concept (Nilsson *et al.*, 2000a). The uncertainty related to the change in forest phytomass is calculated in two different ways (the annual exploitation can be pre-processed differently); however, each calculation is subjected to the overall condition of consistency.
	Ia	Standing Stock	
	Step 1	Basic Data with Reference to Standing Stock	
	Step 2	From (m^3 o.b. / ha) to (tC) (total tree biomass) — In Consideration of Uncertainties	
	Ib	Uncertainty of Forest Phytomass Change (Calculation #1: Annual exploitation data not made "AWB–AFI" consistent initially)	
	Step 1	Basic Data with Reference to Gross Annual Increment and Annual Exploitation	
	Step 2	From (m^3 o.b. / ha / yr) to (tC yr^{-1}) (changes in total tree biomass) — Including Uncertainties	
	Step 3	Application of the IIASA Uncertainty Concept following Nilsson *et al.* (2000a)	
	Ic	Uncertainty of Forest Phytomass Change (Calculation #2: Annual exploitation data made "AWB–AFI" consistent initially)	
	Step 1	Basic Data with Reference to "AWB–AFI" Consistent Annual Exploitation	
	Step 2	From (m^3 o.b. / ha / yr) to (tC yr^{-1}) (changes in total tree biomass) — Including Uncertainties	
	Step 3	Application of the IIASA Uncertainty Concept following Nilsson *et al.* (2000a)	
	II	Soil	
	Step 1	Basic Data with Reference to Soil Carbon (≤ 50 cm)	
	Step 2	From (tC / ha) to (tC) — Including Uncertainties	

Worksheet	Title		Contents
Harvest Residues	**Harvest Residues Transferred to the Litter Pool of Austria's Exploitable Forest**		The “harvest residues–to–total tree biomass” ratio is determined and, with its help, the amount of harvest residues that are transferred to the litter/soil pool.
	I	Austria's "Harvest Residues-to-Total Tree Biomass" Ratio	
	Step 1	Data in Accordance with Austria's Wood Supply *(Holzaufkommen)* in (tC yr^{-1})	
	Step 2	"AWB–AFI" Consistent Total Tree Biomass Affected by Austria's Harvest	
	Step 3	Calculation of the "Harvest Residues–to–Total Tree Biomass" Ratio	
	II	Harvest Residues Transferred to the Litter Pool	
	Step 1	Calculation of the Harvest Residues in (tC yr^{-1})	
Bridge to ACBM II	**Terminological Correspondences: ACBM II versus ACDb**		Fluxes (and their uncertainties) are determined in accordance with their appearance and level of aggregation in the ACBM II model. To facilitate the use of the ACDb FOREST module in the context of the ACBM, a dictionary in the form of two tables lists the terminological correspondences between the ACDb and the ACBM.
	I	Missing ACBM II–ACDb Flux Correspondences	
	Step 1	FP_industrial roundwood	
	Step 2	FE_biomass	
	Step 3	PE_forest biomass	
	II	Terminological Correspondences: ACBM II versus ACDb	
	Step 1	Linking up: ACBM II: FOREST Module with ACDb: FOREST Module	

A-1.2 PROD Module

Worksheet	Title		Contents
General	**Database for Assessment of the Austrian Carbon Balance (ACDb): PROD**		Information header
Austria's Production Balance	**Austria's PRODUCTION Balance in Carbon Units, In Consideration of Uncertainty**		The 1990 material and carbon flow balances of the PROD module are determined.
	I	Wood Processing	
	II	Food and Feed Processing	
	III	Chemical Production	
	IV	Steel Production	
	V	Cement and Lime Production	
Uncertainties and Aggregation	**Uncertainties and Aggregation**		The uncertainties underlying the 1990 carbon balance of the PROD module are assembled (from Worksheet "Uncertainty Calculation" below) and are aggregated.
	I	Wood Processing	
	II	Food and Feed Processing	
	III	Chemical Production	
	IV	Steel Production	
	V	Cement and Lime Production	
	---	Aggregated Carbon Flows to and from {PROD}	
I. Wood Proc + III. Chem Prod	**Sub-balance I. Wood Processing and III. Chemical Production**		Information relevant to establishing the sub-balances for wood processing and chemical production is assembled.
	---	Conversion Factors from Different Sources	
	---	Finding an Average Carbon Content Factor for Wood Products	
	---	Finding an Average Carbon Content for Plastics	
	---	Finding the Content of Plastics in Products	
	---	Finding an Average Carbon Content Factor for Pulp and Paper	
II. Food and Feed Processing	**Sub-balance II. Food and Feed Processing**		Information relevant to establishing the sub-balance for food and feed processing is assembled.
	---	Agricultural Carbon Production	
	---	MFA Time Series Data 1990	

Worksheet		Title	Contents
V. Cement and Lime Production	**Sub-balance V. Cement and Lime Production: Cement**		Information relevant to establishing the sub-balance for cement and lime production is assembled.
	---	Stoichiometric Calculation	
	---	Austrian Federal Environment Agency – Data	
	---	ORNL Internet Database	
	---	UBA Conversion from Cement Raw Dust *(Rohmehl)* to Cement Clinker *(Klinker)*	
	---	Relation of Cement Raw Material to Raw Dust *(Rohmehl)*	
	---	Upper Boundary: Calculation from Raw Material	
	---	Lower Boundary: Calculation from Raw Dust	
	---	Weighted Average and Uncertainty Calculation for Cement Raw Material	
Uncertainty Calculation	**Uncertainty Calculation**		The uncertainties underlying the 1990 carbon balance of the PROD module are specified (for Worksheet "Uncertainties and Aggregation" above).
	II	Food and Feed Processing	
	I	Wood Processing	
	III	Chemical Production	
	IV	Steel Production	
	V	Cement and Lime Production	
MFA 90-92 Mineral	**Material Flow Balance for Austria in 1990 and 1992: Minerals *(Materialflußrechnung Österreich 1990 und 1992: Mineralische Materialien)***		Austria's 1990 and 1992 material flow accounting is scrutinized with respect to minerals and used in establishing the 1990 carbon balance of the PROD module.
	---	Domestic Primary Extraction *(Inländische Primärentnahme)*	
	---	Import *(Import)*	
	---	Production *(Verarbeitung)*	
	---	Final Demand of Households *(Endnachfrage Haushalte)*	
	---	Stock *(Bestand)*	
		Export *(Export)*	

Worksheet	Title	Contents
MFA 90-92 Biomass	**Material Flow Balance for Austria in 1990 and 1992: Biomass** ***(Materialflußrechnung Österreich 1990 und 1992: Biomasse)***	Austria's 1990 and 1992 material flow accounting is scrutinized with respect to biomass and used in establishing the 1990 carbon balance of the PROD module.
	--- Import *(Import)*	
	--- Wood Production *(Forstliche Produktion)*	
	--- Agricultural Production *(Pflanzliche Produktion)*	
	--- Livestock Production *(Tierische Produktion)*	
	--- 2nd Production Level *(2. Verarbeitungsstufe)*	
	--- Final Demand *(Endnachfrage)*	
	--- Stock *(Bestand)*	
	--- Export *(Export)*	
MFA 90-92 Fossil	**Material Flow Balance for Austria in 1990 and 1992: Coal, Oil, Gas** ***(Materialflußrechnung Österreich 1990 und 1992: Kohle, Erdöl, Erdgas)***	Austria's 1990 and 1992 material flow accounting is scrutinized with respect to fossil fuels (coal, oil, gas) and used in establishing the 1990 carbon balance of the PROD module.
	--- Import *(Import)*	
	--- Mining, Oil and Gas Production *(Bergbau, Erdöl- und Erdgasförderung)*	
	--- Refinery *(Raffinerie)*	
	--- Coking Plant *(Kokerei)*	
	--- Blast Furnace *(Hochofen)*	
	--- Supply of Electricity and Heating *(Elektrizitäts- und Wärmeversorgung)*	
	--- Chemical Industry *(Chemische Industrie)*	
	--- Final Demand *(Endverbrauch)*	
	--- Stock *(Lager)*	
	--- Export *(Export)*	

A-1.3 CONSU/WASTE Module

Worksheet		Title	Contents
General	**Database for Assessment of the Austrian Carbon Balance (ACDb): CONSU/WASTE**		Information header
Austria's Consu-Waste Balance	**Austria's CONSUMPTION and WASTE Balance in Carbon Units, In Consideration of Uncertainty**		The 1990 material and carbon flow balances of the CONSU/WASTE module are determined.
	I	I. Wood Utilization (non-energetic)	
	II	Food Supply	
	III	Plastic and Chemical Use	
	IV	Steel Production	
	V	Cement and Lime Production	
Uncertainties and Aggregation	**Uncertainties and Aggregation**		The uncertainties underlying the 1990 carbon balance of the CONSU/WASTE module are specified and aggregated.
	I	Wood Utilization (non-energetic)	
	II	Food Supply	
	III	Plastic and Chemicals	
	---	Aggregated Carbon Flows to and from {CONSU/WASTE}	
C Conversion + Expansion	**Carbon Conversion**		Carbon conversion factors for chemicals, food, textiles, and pulp and paper are specified.
	---	Conversion Factors from Different Sources	
	---	Finding an Average Carbon Content for Plastics	
	---	Finding the Content of Plastics in Products	
	---	Finding an Average Carbon Content Factor for Pulp and Paper	
Waste Management	**Waste Management**		The waste management of Austria's households and industries are specified in terms of carbon.
	---	Household	
	---	Industry	

A-1.4 AGRO Module

Worksheet		Title	Contents
General	**Database for Assessment of the Austrian Carbon Balance (ACDb): AGRO**		Information header
LUC Austria	**Land-use and Cover in Austria for 1970–1998**		Austria's land-use and cover (LUC) data are made consistent for 1970–1998 and checked with remotely sensed data for 1990/91. The consistent LUC data are used to derive their 1986–1994 rate of change.
	I	Making Austria's Land-use and Cover Data Consistent Following Schidler (1998)	
	Step 1	Basic Data with Reference to Land-use and Cover	
	Step 2	Interpolating the Land-use Change and Cover Data Linearly	
	Step 3	Smoothing the Land-use Change and Cover Data (5-yr Moving Window)	
	Step 4	Compelling Consistency	
	II	Grasping the Inherent Inconsistency	
	Step 1	Comparing Land-use and Cover Data [I: Step 1 (or I: Step 2) with I: Step 4]	
	III	Calculating the 1986–1994 Rate of Change in Austria's LUC	
	Step 1	Calculating the 1986–1994 Rate of Change in Austria's LUC from I: Step 4	
	IV	Checking Austria's Consistent LUC Data with Remotely Sensed Data for 1990/91	
	Step 1	Basic RS Data with Reference to Land-use and Cover	
	Step 2	Rearranging Austria's 1990/91 Consistent LUC Data from I: Step 4	
	Step 3	Comparing Land-use and Cover Data (IV: Step 1 with IV: Step 2)	
LUC Provinces	**Land-use and Cover in Austria's Provinces for 1988–1992**		Austria's provincial, 1988–1992 land-use and cover (LUC) data are made consistent. In so doing, their means are assigned to the year 1990.
	I	Austria's Land-use and Cover by Province — Basic Data	
	Step 1	Basic Data with Reference to Land-use and Cover	
	Step 2	Basic Data Cross-Check	
	II	Making the Provincial LUC Data of I: Step 1 Consistent	
	Step 1	Determining Area Percentages to Be Assigned to 1990	
	Step 2	Determining 1990 Areas	
	III	Grasping the Inherent Inconsistency	
	Step 1	Comparing Land-use and Cover Data [I: Step 1 with II: Step 2]	
Plant Prod C Conv	**Dry Matter and Carbon Conversion Factors Associated With the Harvest of Field Crops and Other Plants**		The dry matter and carbon conversion factors, including their underlying uncertainties, are determined for groups of field crops and other plants.
	I	From (t fm) (fresh matter) to (tC) (carbon content)	
	Step 1	From (t fm) (fresh matter) to (t dm) (dry matter)	
	Step 2	From (t dm) (dry matter) to (tC) (carbon content)	
	Step 3	From (t fm) (fresh matter) to (tC) (carbon content) — Mean Values and Uncertainties for Groups of Field Crops and Other Plants	

Worksheet	Title		Contents
Field Crop Prod	**Plant Production on Austria's Arable Land including Commercially Used Gardens for 1980–1999**		The production of groups of field crops and other plants on Austria's land including commercially used gardens is determined for 1980–1999 in terms of carbon. Consistency is compelled in regard to the total area involved.
	I	Basic Data Related to the Production of Field Crops on Austria's Arable Land	
	Step 1	Field Crops on Austria's Arable Land: Area, Domestic Harvest, Import and Export, as Provided by FIAE (Contact: C. Grohsebner)	
	Step 2	Data of Step 1 Compiled According to Groups of Field Crops and Other Plants	
	II	From (t fm) (fresh matter, original moisture content) to (tC) (mass of carbon)	
	Step 1	Conversion of Domestic Harvest, Import and Export from (t fm) (fresh matter) to (tC) (mass of carbon) - In Consideration of Uncertainties	
	Step 2	Compelling Areal Consistency	
Fruit + Vine Prod, etc.	**Production of Fruit, Vine and Garden Crops from Austria's Orchards, Vineyards and Gardens for 1980–1999**		The production of fruit, vine and garden crops from Austria's orchards, vineyards and gardens, respectively, is determined for 1980–1999 in terms of carbon. Consistency is compelled in regard to the total areas involved.
	I	Basic Data Related to the Production of Fruit, Vine and Other Plants from Austria's Orchards, Vineyards and Gardens	
	Step 1a	Fruit from Austria's Orchards: Area, Domestic Harvest, Import and Export, as Provided by FIAE (Contact: C. Grohsebner)	
	Step 1b	Vine from Austria's Vineyards: Area, Domestic Harvest, Import and Export, as Provided by FIAE (Contact: C. Grohsebner)	
	Step 1c	Garden Crops from Austria's Gardens: Area and Domestic Harvest	
	Step 1d	Grand Total of I: Steps 1a–c	
	Step 2a	Data of Step 1a Compiled According to Groups of Field Crops and Other Plants	
	Step 2b	Data of Step 1b Compiled According to Groups of Field Crops	
	Step 2c	Data of Step 1c Compiled According to Groups of Field Crops	
	Step 2d	Grand Total of I: Steps 2a–c	
	II	From (t fm) (fresh matter, original moisture content) to (tC) (mass of carbon)	
	Step 1a	Conversion of Domestic Harvest, Import and Export of Fruit from (t fm) (fresh matter) to (tC) (mass of carbon) — In Consideration of Uncertainties	
	Step 1b	Conversion of Domestic Harvest, Import and Export of Vine from (t fm) (fresh matter) to (tC) (mass of carbon) — In Consideration of Uncertainties	
	Step 1c	Conversion of Domestic Harvest of Garden Crops from (t fm) (fresh matter) to (tC) (mass of carbon) — In Consideration of Uncertainties	
	Step 1d	Grand Total of II: Steps 1a–c	
	Step 2a	Compelling Areal Consistency: Orchards	
	Step 2b	Compelling Areal Consistency: Vineyards	
	Step 2c	Compelling Areal Consistency: Gardens	
	Step 2d	Compelling Areal Consistency: Orchards, Vineyards and Gardens — Grand Total of II: Steps 2a–c	

Worksheet	Title		Contents
Hay Prod	**Production of Hay from Austria's Meadows for 1980-1999**		The production of hay from Austria’s meadows is determined for 1980–1999 in terms of carbon. Consistency is compelled in regard to the total area involved.
	I	Basic Data Related to the Production of Hay from Austria's Meadows	
	Step 1	Hay from Austria's Meadows: Area and Domestic Harvest, as Provided by FIAE (Contact: C. Grohsebner)	
	Step 2	Data of Step 1 Compiled According to Groups of Field Crops and Other Plants	
	II	From (t fm) (fresh matter, original moisture content) to (tC) (mass of carbon	
	Step 1	Conversion of Domestic Harvest of Hay from (t fm) (fresh matter) to (tC) (mass of carbon) — In Consideration of Uncertainties	
	Step 2	Compelling Areal Consistency	
Harv Use	**Use of Austria's Domestic Harvest for 1980–1999**		The use of Austria’s domestic harvest is determined for 1980–1999, resolving (1) harvest to PROD, (2) harvest to ENERGY, (3) harvest for private consumption (food), and (4) harvest for husbandry (feed).
	I	Plant Production on Austria's Arable Land including Commercially Used Gardens, Orchards, Vineyards, Gardens and Meadows	
	Step 1	Recapitulating Worksheet "Field Crop Prod", II: Step 2 — Austria's Arable Land including Commercially Used Gardens	
	Step 2	Recapitulating Worksheet "Fruit + Vine Prod", II: Step 2a — Orchards	
	Step 3	Recapitulating Worksheet "Fruit + Vine Prod", II: Step 2b — Vineyards	
	Step 4	Recapitulating Worksheet "Fruit + Vine Prod", II: Step 2c — Gardens	
	Step 5	Recapitulating Worksheet "Hay Prod", II: Step 2 — Meadows	
	Step 6	Sum of I: Steps 1 to 5	
	II	Use of Domestic Harvest: (1) Harvest to PROD and ENERGY; (2) Harvest to Private Consumption; (3) Harvest to Husbandry	
	Step 1	Harvest to PROD and ENERGY	
	Step 2	Harvest to Private Consumption	
	Step 3	Harvest to Husbandry	
	III	Specifying Domestic Harvest to PROD and ENERGY	
	Step 1	Harvest to ENERGY	
	Step 2	Harvest to PROD	
	IV	Re-resolving the Use of Domestic Harvest (Cf. II: Steps 1–3): (1) Harvest to PROD; (2) Harvest to ENERGY; (3) Harvest to Private Consumption; (4) Harvest to Husbandry	
	Step 1	Harvest to PROD	
	Step 2	Harvest to ENERGY	
	Step 3	Harvest to Private Consumption	
	Step 4	Harvest to Husbandry	
	Step 5	Sum of IV: Steps 1 to 4	

Worksheet	Title		Contents
Coprod + HRR C Conv	**Conversion Factors for Coproducts and Harvest and Root Residues of Field Crops and Other Plants**		The dry matter and carbon conversion factors, including their underlying uncertainties, are determined for coproducts and harvest and root resiues (the latter for field crops without field forage growing/grassland management, and for field forage growing/grassland management separately).
	I	Harvest Practices and/or Assumptions	
	Step 1	Use of Coproducts, and Harvest and Root Residues	
	II	Harvest-to-Coproduct Mass Ratio	
	Step 1	Grain-to-Straw, Tuber-to-Vine/Foliage and Seed-to-Pulp Ratios	
	III	From (t fm) (fresh matter) to (t dm) (dry matter)	
	Step 1	From (t fm) (fresh matter) to (t dm) (dry matter)	
	IV	On the Basis of Dry Matter	
	Step 1	HRR-to-Harvest Mass Ratio	
	Step 2	Harvest Density in Units of (t dm / ha)	
	Step 3	Coproduct Density in Units of (t dm / ha)	
	Step 4	HRR Density in Units of (t dm / ha)	
	V	From (t dm) (dry matter) to (tC) (carbon content)	
	Step 1	Carbon Content of Coproducts	
	Step 2	Carbon Content of HRRs	
	VI	Carbon Density — Mean Values and Uncertainties for Coproducts and HRRs	
	Step 1	Carbon Density for Coproducts	
	Step 2a	Carbon Density for HRRs: Field Crops (Excluding Field Forage Growing and Grassland Management)	
	Step 2b	Carbon Density for HRRs: Grass and Grass-clover, Lucerne, etc. (Field Forage Growing and Grassland Management)	

Worksheet		Title	Contents
Coprod + HRR Prod	**Production of Coproducts, and Harvest and Root Residues on Austria's Arable Land and Grassland for 1980–1999**		The production of coproducts, and harvest and root residues on Austria's arable land and grassland, respectively, is determined for 1980–1999 in terms of carbon. Consistency is compelled in regard to the total areas involved.
	I	Production of Coproducts on Austria's Arable Land	
	Step 1	Reported Data in (t dm)	
	Step 2	Coproducts (w Grain Maize Straw) in (tC) — In Consideration of Uncertainties	
	Step 3	Considering Areal Uncertainty (w Grain Maize Straw)	
	IIa	Production of Harvest and Root Residues on Austria's Arable Land	
	Step 1	Harvest and Root Residues (w/o Grain Maize Straw) in (tC) — In Consideration of Uncertainties	
	Step 2	Considering Areal Uncertainty (w/o Grain Maize Straw)	
	Step 3	Considering Grain Maize Straw	
	IIb	Production of Harvest and Root Residues on Austria's Meadows	
	Step 1a	Harvest and Root Residues on Austria's Intensively Used Meadows in (tC) — In Consideration of Uncertainties	
	Step 1b	Harvest and Root Residues on Austria's Extensively Used Meadows in (tC) — In Consideration of Uncertainties	
	Step 1c	Harvest and Root Residues on Austria's Intensively and Extensively Used Meadows in (tC) — In Consideration of Uncertainties	
	Step 2a	Considering Areal Uncertainty for Austria's Intensively Used Meadows	
	Step 2b	Considering Areal Uncertainty for Austria's Extensively Used Meadows	
	Step 2c	Considering Areal Uncertainty for Austria's Intensively and Extensively Used Meadows	
	IIc	Production of Harvest and Root Residues on Austria's Pastures including Alpine Grassland	
	Step 1	Harvest and Root Residues on Austria's Pastures including Alpine Grassland in (tC) — In Consideration of Uncertainties	
	Step 2	Considering Areal Uncertainty for Austria's Pastures including Alpine Grassland	

Worksheet		Title	Contents
Coprod Use	**Use of Coproducts from Austria's Arable Land for 1980–1999**		The use of Austria’s coproducts is determined for 1980–1999, resolving (1) straw and fodder beet foliage for husbandry, (2) straw to ENERGY, and (3) grain maize straw as harvest and root residues.
	I	Production of Coproducts (Straw w Grain Maize Straw, Fodder Beet Foliage) on Austria's Arable Land	
	Step 1	Recapitulating Worksheet "Coprod + HRR Prod", I: Step 3	
	II	Use of Domestic Coproducts: (1) Straw to Husbandry, ENERGY and ATMO; (2) Grain Maize Straw to Harvest and Root Residues; (3) Fodder Beet Foliage to Husbandry	
	Step 1	Straw to Husbandry, ENERGY and ATMO	
	Step 2	Grain Maize Straw to Harvest and Root Residues	
	Step 3	Fodder Beet Foliage to Husbandry	
	III	Specifying Straw to Husbandry, ENERGY and ATMO	
	Step 1	Straw to ENERGY	
	Step 2	Straw to ATMO	
	Step 3	Straw to Husbandry	
	IV	Re-resolving the Use of Domestic Coproducts (Cf. II: Steps 1–3): (1) Straw and Fodder Beet Foliage to Husbandry; (2) Straw to ENERGY; (3) Grain Maize Straw to Harvest and Root Residues	
	Step 1	Straw and Fodder Beet Foliage to Husbandry	
	Step 2	Straw to ENERGY	
	Step 3	Straw to ATMO	
	Step 4	Grain Maize Straw to Harvest and Root Residues	
	Step 5	Sum of IV: Steps 1 to 4	

Worksheet		Title	Contents
Non-Forest Phytomass		**Austria's Non-Forest Phytomass for 1980–1999**	Austria’s non-forest phytomass is determined, resolving (1) arable land including commercially used gardens; (2) orchards, vineyards and gardens; (3) meadows; (4) pastures including alpine grassland; and (5) other productive areas (abandoned grassland). (With respect to the latter, plantations for biomass production, tree nurseries and gardens, and Christmas tree plantations are not considered for reasons of data availability).
	I	Austria's Arable Land including Commercially Used Gardens	
	Step 1a	Aboveground Phytomass: Field Crops	
	Step 1b	Aboveground Phytomass: Coproducts	
	Step 2	At and Belowground Phytomass: Harvest and Root Residues	
	Step 3	Total Phytomass: Arable Land including Commercially Used Gardens (Sum of I: Steps 1 to 2)	
	II	Austria's Orchards, Vineyards and Gardens	
	Step 1	Aboveground Phytomass: Fruit, Vine and Garden Crops	
	Step 2	Total Phytomass: Above- and Belowground Phytomass	
	Step 3	Total Phytomass: Orchards, Vineyards and Gardens (Sum of II: Steps 1 to 2)	
	III	Austria's Meadows	
	Step 1	Aboveground Phytomass: Hay	
	Step 2	At and Belowground Phytomass: Harvest and Root Residues	
	Step 3	Total Phytomass: Meadows (Sum of III: Steps 1 to 2)	
	IV	Austria's Pastures including Alpine Grassland	
	Step 1	Aboveground Phytomass: Feed Uptake	
	Step 2	At and Belowground Phytomass: Harvest and Root Residues	
	Step 3	Total Phytomass: Pastures including Alpine Grassland (Sum of IV: Steps 1 to 2)	
	V	Austria's Other Productive Areas: Abandoned Grassland	
	Step 1	Aboveground Phytomass: Aboveground Phytomass	
	Step 2	Total Phytomass: Above- and Belowground Phytomass	
	Step 3	Total Phytomass: Other Productive Areas: Abandoned Grassland (V: Step 2)	
	VI	Austria's Non-Forested Areas	
	Step 1	Sum of I: Step 3 to V: Step 3	

Worksheet	Title		Contents
Non-Forest NPP	**NPP Associated with Austria's Non-Forested Areas for 1980–1999**		The net primary production associated with Austria's non-forested areas is determined for 1980–1999, resolving (1) arable land including commercially used gardens; (2) orchards, vineyards and gardens; (3) meadows; (4) pastures including alpine grassland; and (5) other productive areas (abandoned grassland). (With respect to the latter, plantations for biomass production, tree nurseries and gardens, and Christmas tree plantations are not considered for reasons of data availability).
	I	NPP Associated with Austria's Arable Land including Commercially Used Gardens	
	Step 1	Arable Land including Commercially Used Gardens	
	II	NPP Associated with Austria's Orchards, Vineyards and Gardens	
	Step 1	Orchards, Vineyards and Gardens	
	III	NPP Associated with Austria's Meadows	
	Step 1	Meadows	
	IV	NPP Associated with Austria's Pastures including Alpine Grassland	
	Step 1	Pastures including Alpine Grassland	
	V	NPP Associated with Austria's Other Productive Areas: Abandoned Grassland	
	Step 1	Other Productive Areas: Abandoned Grassland	
	VI	NPP Associated with Austria's Non-Forested Areas	
	Step 1	Sum of I: Step 1 to V: Step 1	
Synthesis Coeff	**Synthesis Coefficient for the Calculation of FOM Carbon to Soil + Atmosphere**		The synthesis coefficient, including its underlying uncertainty, is determined for the fractionation of (atmospheric and soil) carbon in fresh organic matter.
	I	Reported Synthesis Coefficients for Fresh (Primary) Organic Matter	
	Step 1	Synthesis Coefficient for Harvest and Root Residues	
	Step 2	Synthesis Coefficient for Manure	
	II	Synthesis Coefficients of I: Steps 1 and 2 in Consideration of Uncertainties	
	Step 1	Synthesis Coefficient for Fresh Organic Matter	

Worksheet	Title		Contents
Soil-Atmo Interface	**Carbon to and from the Soil-Atmosphere Interface for 1980–1999**		The carbon fluxes to and from the soil-atmosphere interface are determined for 1980–1999, resolving (1) arable land including commercially used gardens; (2) meadows; (3) pastures including alpine grassland; and (4) other productive areas (abandoned grassland). (Not considered for reasons of data availability are: (a) orchards, vineyards and gardens; and (b) other productive areas like: plantations for biomass production, tree nurseries and gardens, and Christmas tree plantations.) Limiting knowledge gap: Measurements to determine the emissions or removals of CO_2 and other important (carbon-related) direct and indirect GHGs (e.g., CH_4 and NMVOC) by Austria's soils (in consideration of LUC) do not exist.
	Ia	Carbon to the Soil-Atmosphere Interface: Austria's Arable Land including Commercially Used Gardens	
	Step 1	Harvest and Root Residues	
	Step 2	Manure	
	Step 3	Lime from PROD	
	Step 4	Organic Waste from WASTE	
	Step 5	Sum of Ia: Steps 1 to 4	
	Ib	Carbon from the Soil-Atmosphere Interface: Austria's Arable Land including Commercially Used Gardens	
	Step 1	Fresh Organic Matter to Soil (Decomposition)	
	Step 2	Fresh Organic Matter to Atmosphere (Decomposition)	
	Step 3	Soil Respiration (excluding Decomposition)	
	Step 4	Sum of Ib: Steps 1 to 3	
	II	Carbon to and from the Soil-Atmosphere Interface: Austria's Orchards, Vineyards and Gardens	
	IIIa	Carbon to the Soil-Atmosphere Interface: Austria's Meadows	
	Step 1	Harvest and Root Residues	
	Step 2	Manure	
	Step 3	Lime from PROD	
	Step 4	Organic Waste from WASTE	
	Step 5	Sum of IIIa: Steps 1 to 4	
	IIIb	Carbon from the Soil-Atmosphere Interface: Austria's Meadows	
	Step 1	Fresh Organic Matter to Soil (Decomposition)	
	Step 2	Fresh Organic Matter to Atmosphere (Decomposition)	
	Step 3	Soil Respiration (excluding Decomposition)	
	Step 4	Sum of IIIb: Steps 1 to 3	
	IVa	Carbon to the Soil-Atmosphere Interface: Austria's Pastures including Alpine Grassland	
	Step 1	Harvest and Root Residues	
	Step 2	Manure	
	Step 3	Sum of IVa: Steps 1 to 2	
	IVb	Carbon from the Soil-Atmosphere Interface: Austria's Pastures including Alpine Grassland	
	Step 1	Fresh Organic Matter to Soil (Decomposition)	
	Step 2	Fresh Organic Matter to Atmosphere (Decomposition)	

Carbon to and from the Soil-Atmosphere Interface for 1980–1999 *(continued*)	
Step 3	Soil Respiration (excluding Decomposition)
Step 4	Sum of IVb: Steps 1 to 3
Va	Carbon to the Soil-Atmosphere Interface: Austria's Other Productive Areas: Abandoned Grassland
Step 1	Harvest and Root Residues
Step 2	Recapitulating Va: Step 1
Vb	Carbon from the Soil-Atmosphere Interface: Austria's Other Productive Areas: Abandoned Grassland
Step 1	Fresh Organic Matter to Soil (Decomposition)
Step 2	Fresh Organic Matter to Atmosphere (Decomposition)
Step 3	Soil Respiration (excluding Decomposition)
Step 4	Sum of Vb: Steps 1 to 3
VI	Summing Up: Austria's Arable Land including Commercially Used Gardens, Meadows, and Pastures including Alpine Grassland
Step 1	Grand Total Fresh Organic Matter (Ia: Step 5; IIIa: Step 5; IVa: Step 3; Va: Step 2)
Step 2	Grand Total Fresh Organic Matter to Soil (Decomposition) (Ib: Step 1; IIIb: Step 1; IVb: Step 1; Vb: Step 1)
Step 3	Grand Total Fresh Organic Matter to Atmosphere (Decomposition) (Ib: Step 2; IIIb: Step 2; IVb: Step 2; Vb: Step 2)

Worksheet	Title		Contents
Non-Forest Soil C	**Carbon in Austria's Non-Forest Soils, Assigned to 1990**		The carbon in Austria's non-forest soils (0–50 cm) is determined by LUC and Province, and assigned to the year 1990. LUC encompasses: (1) arable land including commercially used gardens; (2) intensively and extensively used grasslands; (3) orchards, vineyards and gardens; (4) plantations (plantations for biomass production, tree nurseries and gardens, and Christmas tree plantations); and (5) other productive areas (abandoned grassland).
	I	Austria's Non-Forest Land-use and Cover LUC) by Province	
	Step 1	Recapitulating the Inconsistent Areas of Worksheet "LUC Provinces" (I: Step 2 and II: Step 1)	
	Step 2	Recapitulating the Consistent Areas of Worksheet "LUC Provinces" (II: Step 2)	
	Step 3	Combining Steps 1 and 2 Towards the Advantage of Introducing Uncertainties	
	II	Total Organic Carbon by LUC and Province	
	Step 1	Assembling Total Organic Carbon Data, in Collaboration with F. Strebl (ARCS) on Consultation with Responsible Austrian Experts	
	Step 2	Total Organic Carbon (0–20 cm) by LUC and Province — In Consideration of Uncertainties	
	Step 3	Total Organic Carbon (20–50 cm) by LUC and Province — In Consideration of Uncertainties	
	III	Soil Bulk Density by LUC and Province	
	Step 1	Soil Bulk Density (0–20 cm) by LUC and Province — In Consideration of Uncertainties (In Collaboration with F. Strebl, ARCS)	
	Step 2	Soil Bulk Density (20–50 cm) by LUC and Province — In Consideration of Uncertainties (In Collaboration with F. Strebl, ARCS)	
	IV	Soil Carbon Density by LUC and Province	
	Step 1	Soil Carbon Density (0–20 cm) by LUC and Province — In Consideration of Uncertainties	
	Step 2	Soil Carbon Density (20–50 cm) by LUC and Province — In Consideration of Uncertainties	
	V	Soil Carbon by LUC and Province	
	Step 1	Soil Carbon (0–20 cm) by LUC and Province — In Consideration of Uncertainties	
	Step 2	Soil Carbon (20–50 cm) by LUC and Province — In Consideration of Uncertainties	
	Step 3	Soil Carbon (0–50 cm) by LUC and Province — In Consideration of Uncertainties	
Livest Prod C Conv	**Dry Matter and Carbon Conversion Factors for Domestic Livestock Products**		The dry matter and carbon conversion factors, including their underlying uncertainties, are determined for groups of livestock products.
	I	From (t fm) (fresh matter) to (tC) (carbon content)	
	Step 1	From (t fm) (fresh matter) to (t dm) (dry matter)	
	Step 2	From (t dm) (dry matter) to (tC) (carbon content)	
	Step 3	From (t fm) (fresh matter) to (tC) (carbon content) — Mean Values and Uncertainties for Groups of Livestock Products	

Worksheet		Title	Contents
Livest Prod	**Austria's Domestic Livestock Production for 1980–1999**		Austria’s production of groups of livestock products is determined for 1980–1999 in terms of carbon.
	I	Basic Data Related to the Production of Goods from Austria's Domestic Livestock	
	Step 1	Austria's Domestic Livestock: Category and Number of Animals, as Provided by FIAE (Contact: P. Handschur)	
	Step 2	Domestic Livestock Production: Meat, Eggs and Milk, as Provided by FIAE (Contact: P. Handschur) and Statistics Austria (Contact: E. Wildling)	
	Step 3	Data of Step 2 Compiled According to Groups of Livestock Products	
	II	From (t fm) (fresh matter, original moisture content) to (tC) (mass of carbon)	
	Step 1	Conversion of Domestic Production, Domestic Use, Import and Export from (t fm) (fresh matter) to (tC) (mass of carbon) — In Consideration of Uncertainties	
Cattle C Balance	**Carbon Maintenance Balance of Austria's Cattle for 1980–1999 (In Consideration of Livestock Management Conditions Around 1990)**		The carbon maintenance balance of Austria’s cattle is determined for 1980–1999, thereby considering livestock management conditions around 1990.
	I	Austria's Cattle by Category and Number	
	Step 1	Cattle by Category and Number	
	II	Feed Demand — In Consideration of Uncertainty:	
	Step 1	Gross Energy Intake in Units of (MJ / d / hd)	
	Step 2	Gross Carbon Intake in Units of (kg C / yr / hd)	
	Step 3	Gross Carbon Intake by Livestock Unit	
	III	CH_4 Emissions — In Consideration of Uncertainty	
	Step 1	Methane Emissions in Units of (kg CH_4 / yr / hd)	
	Step 2	Methane Emissions by Livestock Unit	
	IV	Excretion — In Consideration of Uncertainty	
	Step 1	Volatile Solids in Units of (kg dm / d / hd)	
	Step 2	Degradable Carbon in Units of (kg C / yr / hd)	
	Step 3	Degradable Carbon by Livestock Unit	
	V	Meat and Milk — In Consideration of Uncertainty	
	Step 1	Meat and Milk in Units of (kg C / yr / hd)	
	Step 2	Meat and Milk by Livestock Unit	
	VI	Closing the Balance: CO_2–C to the Atmosphere — In Consideration of Uncertainty	
	Step 1	CO_2–C to Atmosphere in Units of (kg C / yr / hd)	
	Step 2	CO_2–C to the Atmosphere by Livestock Unit	

	Carbon Maintenance Balance of Austria's Cattle for 1980–1999 (In Consideration of Livestock Management Conditions Around 1990) ***(continued)***		
	VII	Summarizing the Balance	
	Step 1	Balance in Units of (kg C / yr / hd)	
	Step 2	Balance in Units of (tC / yr / LU)	
	VIII	Applying the Balance to Dairy and Non-Dairy Cattle for 1980–1999	
	Step 1	In Units of (10^6 tC)	
Pig C Balance	**Carbon Maintenance Balance of Austria's Pigs for 1980–1999**		The carbon maintenance balance of Austria's pigs is determined for 1980–1999.
	I	Austria's Pigs by Category and Number	
	Step 1	Pigs by Category and Number	
	II	Feed Demand — In Consideration of Uncertainty	
	Step 1	Gross Energy Intake in Units of (MJ / d / hd)	
	Step 2	Gross Carbon Intake in Units of (kg C / yr / hd)	
	Step 3	Gross Carbon Intake by Livestock Unit	
	III	CH_4 Emissions — In Consideration of Uncertainty	
	Step 1	Methane Emissions in Units of (kg CH_4 / yr / hd)	
	Step 2	Methane Emissions by Livestock Unit	
	IV	Excretion — In Consideration of Uncertainty:	
	Step 1	Volatile Solids in Units of (kg dm / d / hd)	
	Step 2	Degradable Carbon in Units of (kg C / yr / hd)	
	Step 3	Degradable Carbon by Livestock Unit	
	V	Meat — In Consideration of Uncertainty	
	Step 1	Meat in Units of (kg C / yr / hd)	
	Step 2	Meat by Livestock Unit	
	VI	Closing the Balance: CO_2–C to the Atmosphere — In Consideration of Uncertainty	
	Step 1	CO_2–C to Atmosphere in Units of (kg C / yr / hd)	
	Step 2	CO_2–C to the Atmosphere by Livestock Unit	
	VII	Summarizing the Balance	
	Step 1	Balance in Units of (kg C / yr / hd)	
	Step 2	Balance in Units of (tC / yr / LU)	
	VIII	Applying the Balance to Pigs for 1980–1999	
	Step 1	In Units of (10^6 tC)	

Worksheet	Title		Contents
Other Livest C Balance	**Carbon Maintenance Balance of Austria's Other Livestock for 1980–1999**		The carbon maintenance balances of Austria's other livestock (sheep, goats, horses) are determined for 1980–1999.
	I	Austria's Domestic Livestock Taken into Consideration	
	Step 1	Livestock by Category and Number	
	II	Maintenance Carbon Balance of Austria's Other Livestock — Disregarding Uncertainty	
	Step 1	Closing the Balance: Sheep and Goats	
	Step 2	Closing the Balance: Horses	
	Step 3	Sum of II: Steps 1 to 2	
Livest Feed Intake	**Feed Demand of Austria's Domestic Livestock for 1980–1999**		The feed demand of Austria's livestock (cattle, pigs, sheep, goats, horses, poultry) is determined for 1980–1999. For 1990, the feed demand is balanced with the total feed supply (including feed from PROD). (Note: Feed supply balances for years other than 1990 are not yet possible, because PROD has not yet been balanced for years other than 1990.)
	I	Austria's Domestic Livestock Taken into Consideration	
	Step 1	Livestock by Category and Number	
	II	Feed Demand — In Consideration of Uncertainties for Cattle and Pigs	
	Step 1	Gross Energy and Feed Intake by Livestock	
	Step 2	Feed Demand — In Consideration of Uncertainties for Cattle and Pigs	
	III	Feed Supply	
	Step 1a	Farm Feed of Domestic Harvest from Austria's Arable Land (including Commercially Used Gardens) and Meadows	
	Step 1b	Farm Feed of Domestic Coproducts from Austria's Arable Land (including Commercially Used Gardens)	
	Step 2	Farm Feed of Domestic Milk	
	Step 3	Feed Uptake from Pastures (including Alpine Grassland)	
	Step 4	Feed from PROD	
	Step 5	Sum of III: Steps 1 to 4	
	IV	Feed Balance: Demand (II: Step 2) versus Supply (III: Step 5)	
	Step 1	Feed Balance	

Worksheet	Title		Contents
Livest C Emis	**CH_4 Emissions (Enteric Fermentation, Manure Management) and CO_2 Emissions (Respiration) from Austria's Domestic Livestock for 1980–1999**		The CH_4 (enteric fermentation, manure management) and CO_2 emissions (respiration) from Austria's domestic livestock (cattle, pigs, sheep, goats, horses, poultry) are determined for 1980–1999.
	I	Austria's Domestic Livestock Taken into Consideration	
	Step 1	Livestock by Category and Number	
	II	CH_4 Emissions (Enteric Fermentation, Manure Management) — In Consideration of Uncertainties for Cattle and Pigs	
	Step 1	CH_4 Emission Factor by Livestock	
	Step 2	CH_4 Emissions: Enteric Fermentation	
	Step 3	CH_4 Emissions: Manure Management	
	Step 4	CH_4 Emissions: Enteric Fermentation + Manure Management	
	III	CO_2 Emissions (Respiration) — In Consideration of Uncertainties for Cattle and Pigs	
	Step 1	CO_2 Emissions: Respiration	
	IV	Sum of II: Step 4 and III: Step 1: CH_4 Emissions (Enteric Fermentation, Manure Management) and CO_2 Emissions (Respiration)	
	Step 1	CH_4 Emissions (Enteric Fermentation, Manure Management) and CO_2 Emissions (Respiration)	
Livest Degrad C	**Degradable Carbon from Austria's Domestic Livestock for 1980–1999**		Supply and use of degradable carbon from Austria's livestock (cattle, pigs, sheep, goats, horses, poultry) are determined for 1980–1999. The use of degradable carbon is specified in terms of (1) excretion on Austria's pastures including alpine grassland; (2) excretion and straw for biogas generation; and (3) excretion and straw on Austria's arable land (including commercially used gardens) and meadows.
	I	I. Austria's Domestic Livestock Taken into Consideration	
	Step 1	Livestock by Category and Number	
	II	Supply of Degradable Carbon (Excretion, Straw) — In Consideration of Uncertainties for Cattle and Pigs	
	Step 1a	Volatile Solids by Livestock	
	Step 1b	Degradable Carbon: Excretion — In Consideration of Uncertainties for Cattle and Pigs	
	Step 2	Degradable Carbon: Straw	
	Step 3	Total Degradable Carbon (Excretion, Straw)	
	III	Use of Degradable Carbon (Excretion, Straw)	
	Step 1	Degradable Carbon (Excretion) on Austria's Pastures (including Alpine Grassland)	
	Step 2	Degradable Carbon (Excretion, Straw) for Biogas	
	Step 3	Degradable Carbon (Excretion, Straw) on Austria's Arable Land (including Commercially Used Gardens) and Meadows	
	Step 4	Total Degradable Carbon (Excretion, Straw)	

Worksheet	Title		Contents
C to Energy	**Supply of Carbon from Austria's Agriculture for Bioenergetic Purposes for 1980–1999**		The 1980–1999 supply of carbon from Austria's agriculture for bio-energetic purposes accounted under ENERGY is recapitulated: Rape and sunflower seeds for the production of biodiesel, straw for burning, and degradable carbon (livestock excretion and straw) for the production of biogas.
	I	Supply of Bioenergy	
	Step 1	Recapitulating Worksheet "Harv Use" (IV: Step 2): Harvest to Energy	
	Step 2	Recapitulating Worksheet "Coprod Use" (IV: Step 2): Coproducts to Energy	
	Step 3	Recapitulating Worksheet "Livest Degrad C" (III: Step 2): Excretion + Straw to Energy	
	Step 4	Sum of I: Steps 1 to 3	
Bridge to ACBM II	**Terminological Correspondences: ACBM II versus ACDb**		Pools and fluxes (and their uncertainties) are recapitulated in accordance with their appearance and level of aggregation in the ACBM II model. To facilitate the use of the ACDb AGRO module in the context of the ACBM, a dictionary in the form of two tables lists the terminological correspondences between the ACDb and the ACBM.
	I	Terminological Correspondences: ACBM II versus ACDb	
	Step 1	Linking up: ACBM II: AGRO Module with ACDb: AGRO Module	

A-1.5 ENERGY Module

Worksheet	Title		Contents
General	**Database for Assessment of the Austrian Carbon Balance (ACDb): ENERGY**		Information header
Bio-energy, etc.	**Austria's Bio-energy and Combustible Waste in 1990 and 1997**		As a preparatory step towards accounting carbon emissions differently, Austria's 1990 and 1997 consumption of bio-energy (and combustible waste) is recapitulated: under FCA as applied by the ACDb, and under PCA as.applied officially (i.e., by the Austrian Federal Environment Office).
	I	Austria's Consumption of Bio-energy and Combustible Waste in 1990 and 1997	
	Step 1	Type of Bio-energy and Combustible Waste Covered by ACDb	
	Step 2	Consumption of Bio-energy and Combustible Waste in 1990 and 1997	
	II	Austria's Consumption of Bio-energy and Combustible Waste in 1990 According to AGRO, FOREST and CONSU/WASTE	
	Step 1	Consumption of Bio-energy and Combustible Waste in 1990 According to AGRO, FOREST and CONSU/WASTE	
	III	Towards Full Carbon Accounting (FCA) of Bio-energy, Consistent with Austria's Official Reporting (First-order Approximation)	
	Step 1	Towards Full Carbon Accounting of Bio-energy: Evaluating I: Step 2 and II: Step 1	
Parameter Aggreg	**Uncertainty of Activity Data and Emission Factors**		The uncertainties underlying Austria's 1990 and 1997 activity data and emission factors are assembled.
	I	Uncertainty of Activity Data and Emission Factors Grouped According to IPCC '96 — Following Winiwarter and Orthofer (2000) and Winiwarter and Rypdal (2001)	
	Step 1	Uncertainty of Activity Data and Emission Factors	
SNAP97–IPCC96	**Austria's Emissions (CO_2, CH_4, N_2O) for 1990 and 1997**		As a preparatory step towards accounting carbon emissions fully or partially, Austria's officially reported CO_2, CH_4, and N_2O emissions in 1990 and 1997 are preliminarily aggregated according to the IPCC '96.
	I	Initial Aggregation of Emissions According to IPCC '96 — Following Winiwarter and Orthofer (2000) and Winiwarter and Rypdal (2001)	
	Step 1	Activity Data and Emissions	
Emis + Unc [IPCC-FCA]	**Austria's Emissions (CO_2, CH_4, N_2O) including Uncertainties for 1990 — Following IPCC '96 and Using FCA (ACDb)**		Following the IPCC '96, Austria's 1990 and 1997 CO_2, CH_4, and N_2O emissions including uncertainties are determined on the basis of FCA.
	I	Calculation of Emissions and Uncertainties — Following IPCC '96 and Using Full Carbon Accounting (FCA), as Applied by the ACDb	
	Step 1	Calculation of Aggregated Activities and Emission Factors in Support of Step 2	
	Step 2	Calculation of Emissions and Uncertainties in (t GHG), (tC) and (t CO_2 eq.)	

Worksheet	Title		Contents
Emis + Unc [IPCC-PCA]	**Austria's Emissions (CO_2, CH_4, N_2O) including Uncertainties for 1990 — Following IPCC '96 and Using PCA (FEA)**		Following the IPCC '96, Austria's official 1990 and 1997 CO_2, CH_4, and N_2O emissions are recapitulated (i.e., on the basis of PCA) and their uncertainties are determined.
	I	Calculation of Emissions and Uncertainties — Following IPCC '96 and Using Partial Carbon Accounting (PCA), as Applied by the Austrian Federal Enviroment Agency (FEA)	
	Step 1	Calculation of Aggregated Activities and Emission Factors in Support of Step 2	
	Step 2	Calculation of Emissions and Uncertainties in (t GHG), (tC) and (t CO_2 eq.)	
Bridge to ACBM II	**Austria's Emissions (CO_2, CH_4) including Uncertainties for 1990 — Following the System Boundaries of the ACDb and the ACBM II**		Considering the system boundaries of the ACDb and the ACBM II, Austria's 1990 and 1997 CO_2 and CH_4 emissions including uncertainties are determined (i.e., on the basis of FCA).
	I	Calculation of Emissions and Uncertainties — Following IPCC '96 and Using Full Carbon Accounting (FCA), as Applied by the ACDb	
	Step 1	Calculation of Aggregated Activities and Emission Factors in Support of Step 2	
	Step 2	Calculation of Emissions and Uncertainties in (t GHG), (tC) and (t CO_2 eq.)	

Appendix 2: LULUCF Under the Kyoto Protocol (First Commitment Period)

Table A-2.1 LULUCF under the Kyoto Protocol (First Commitment Period): Some issues of relevance to the ACDb Study. Sources: FCCC (2001a, b).

LULUCF under the Kyoto Protocol (First Commitment Period)		
Some Issues of Relevance to the ACDb Study	**Article 3.3**	**Article 3.4**
Eligible Activities	Afforestation, reforestation, and deforestation (ARD)	Forest management Agricultural activities: - Cropland management - Grazing land management - Revegetation
Eligibility Conditions	Since 1990; direct human-induced	Since 1990; human-induced
Accounting Options	Shall be used	Any or all may be used
Accounting	Carbon stock changes between 2008 and 2012	Forest Management: Carbon stock changes between 2008 and 2012, but in consideration of possible debits under Art. 3.3 and country specific caps Agricultural Activities: Net-net (emissions - removals) in regard to commitment period and base year
Under Art. 6 (JI), 12 (CDM), and 17 (ET)	All articles: The use of these trading mechanisms shall be supplemental to domestic action, which shall constitute a significant element of the effort made by each Annex I country. Art. 12: See below Art. 17: Annex I countries must maintain a commitment period reserve of their GHG budgets to prevent overselling and, as a consequence, noncompliance.	
Under Art. 12 (CDM)	Limited to afforestation and reforestation; 1% cap on purchases of these credits for each Annex I country Modalities still to be addressed include non-permanence, additionality, leakage, scale, uncertainties, socio-economic and environmental impacts (including impacts on bio-diversity and natural ecosystems).	---

Appendix 3: Land Use and Cover in Austria for 1970–1998 and Its 1986–94 Rate of Change

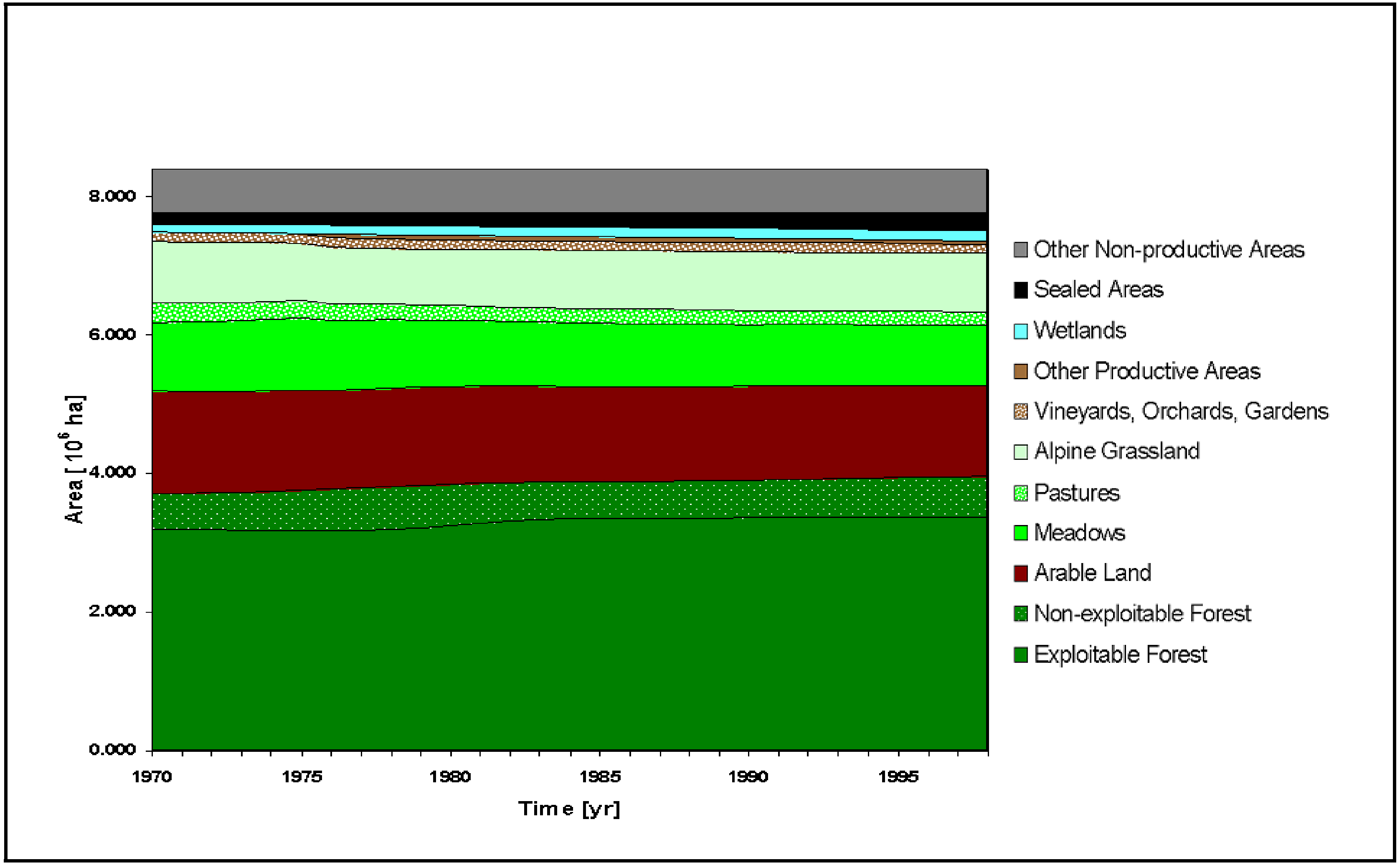

Figure A-3.1: Land use and cover in Austria for 1970–1998.

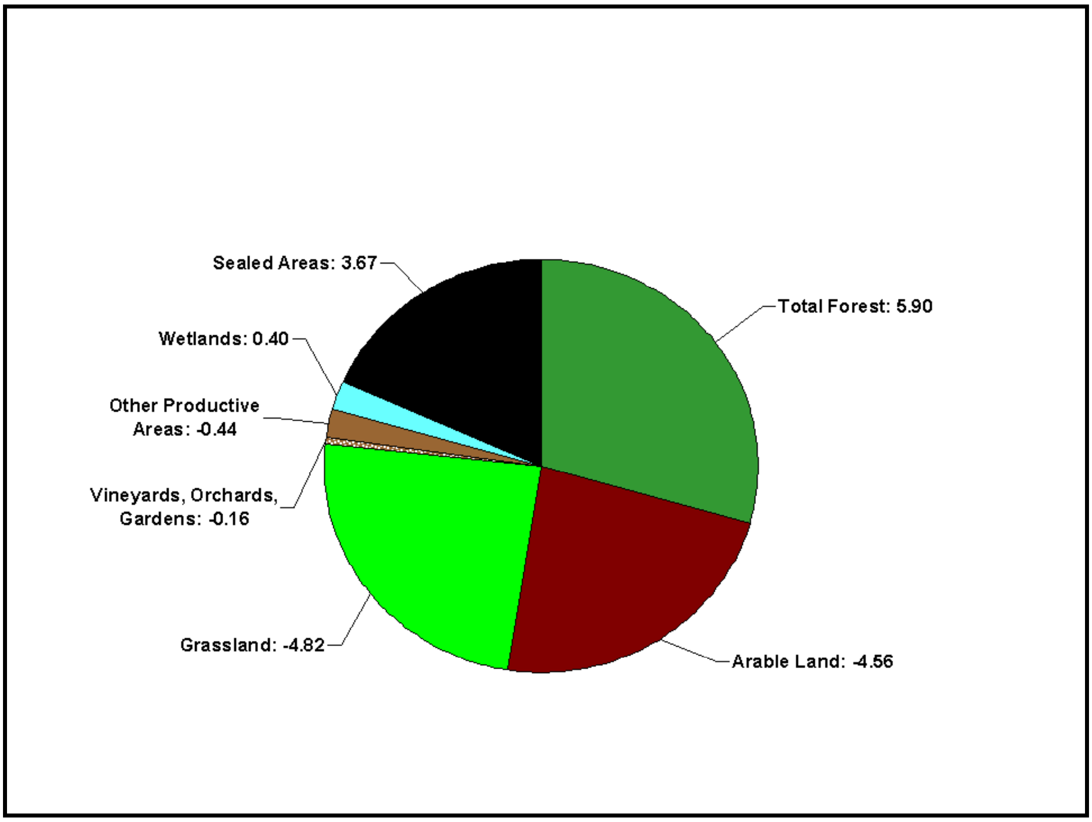

Figure A-3.2: 1986–94 rate of change in Austria's LUC [10^3 ha/yr].