International Institute for
Applied Systems Analysis
Schlossplatz 1
A-2361 Laxenburg, Austria

Tel: +43 2236 807 342
Fax: +43 2236 71313
E-mail: publications@iiasa.ac.at
Web: www.iiasa.ac.at

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Contribution to a Carbon Consistent Database for Austria

Andreas Geisler (andreas.geisler@bmbwk.gv.at)
Matthias Jonas (jonas@iiasa.ac.at)

Approved by

Sten Nilsson
Leader, Forestry Project

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Contents

Abstract

Andreas Geisler participated in IIASA's 1999 Young Scientists Summer Program (YSSP) and this paper summarizes his research. He was supervised by Matthias Jonas, research scholar in IIASA's Forestry (FOR) Project. Geisler's YSSP research task contributes to IIASA's research on Full Carbon Accounting and to the *Database for Assessment of Carbon Balance Modeling in Austria* study, work that commenced in June 1999.

The boundary conditions in setting up the Austrian carbon database are that it:

- is carbon consistent;
- satisfies the needs of Austria's carbon modeling community; and
- is consistent with FOR's existing database on Russia.

The objectives of the three-month YSSP task were to:

- create a database framework,
- fill the database with some national data sets;
- track down carbon inconsistencies; and
- discuss options on how these can be overcome.

However, the first objective had to be slightly changed during the course of the work, since available data sources posed some problems in creating the database setting. Therefore, after discussions with the research institutions employed with building the *Austrian Carbon Balance Model* (which are: Austrian Research Centers Seibersdorf; Institute for Industrial Ecology, St. Pölten; and Joanneum Research, Graz), as well as with other Austrian research institutions and experts (see Acknowledgments) the objective was changed towards trying to obtain consistency of the relevant carbon flows on a national level. Therefore, as a first step, a carbon balance framework on three different levels was established. In view of the limited time available, some Austrian wood related carbon flows were quantified with regard to consistency principles and the underlying options to overcome inconsistencies are very well reported. The carbon consistent database will be completed by mid 2001 and will put Austria a step forward in Full Carbon Accounting.

Acknowledgments

The authors wish to thank the Austrian Federal Ministry of Education, Science and Culture, the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management, and the Austrian Academy of Sciences for financially supporting this important research study. We would also like to express our sincere gratitude to all of the researchers and experts who provided us with information, knowledge and expertise. In particular, we would like to thank Susanne Schidler, Hermann Schmidt-Stejskal, Francois Schneider and Andreas Windsperger from the Institute of Industrial Ecology in St. Pölten, Austria; Ernst Gebetsroither, Martin Gerzabek, Friederike Strebl and Rudolf Orthofer from the Austrian Research Centers Seibersdorf; Bernhard Schlamadinger and Hannes Schwaiger from Joanneum Research, Graz, Austria; Fridolin Krausmann and Helga Weisz from the Institute for Interdisciplinary Studies of Austrian Universities, as well as Ms. Deutsch and Hannes Hameseder from Statistics Austria.

About the Authors

Andreas Geisler has worked at the Institute of Ecology and Nature Conservation at the University of Vienna for several years. The main topics of his research work are material flow analysis of municipalities, in particular nitrogen, as well as the development of new methodological approaches for evaluating land use from an ecological point of view. At present, Andreas Geisler works as a scientific officer in the Department of Environmental Sciences of the Federal Ministry of Education, Science and Culture.

Matthias Jonas is a research scholar in the Forestry Project at IIASA. The main topics of his research work range from climate change impacts to scaling issues with reference to the soil-atmosphere interface and most recently to research related to the carbon cycle.

Contribution to a Carbon Consistent Data for Austria

Andreas Geisler and Matthias Jonas

1 Introduction

The world is facing the serious problem that the main greenhouse gas concentrations in the atmosphere (e.g., CO_2, CH_4, N_2O, HCFC-22, CF_4, SF_6) continue to increase (IPCC, 1995; 1996b). Only the increasing CFC-11 concentration could so far be stopped (*Table 1*). Direct radiative forcing is due primarily to increases in the concentrations of CO_2 and CH_4 (64% and 0.19% in 1992, respectively) (IPCC, 1996a). Hence, the main interest is given to understanding the global carbon cycle. *Figure 1* indicates the increase in atmospheric CO_2 concentration at Mauna Loa, Hawaii between 1958 and 1996. The CO_2 concentration is expected to reach 382 ppmv in 2010 and will, depending upon reduction measures and model projections, increase further to concentrations between approximately 500 and 1000 ppmv at the end of the 21st century (*Table 1*).

Table 1: Development of greenhouse gas concentrations and their present rate of change. Sources: IPCC (1996a; 2001), Bolin (1998).

	CO_2	**CH_4**	**N_2O**	**CFC-11**	**HCFC-22**	**CF_4**
Pre-industrial concentration	approx. 280 ppmv	approx. 700 ppbv	approx. 275 ppbv	zero	zero	zero
Concentration in 1994 in 2000	358 ppmv	1720 ppbv 1760 ppbv	312 ppbv 316 ppbv	268 pptv	110 pptv	72 pptv
Rate of concentration change	1.5 ppmv/yr	10 ppbv/yr	0.8 ppbv/yr	0 pptv/yr	5 pptv/yr	1.2 pptv/yr
Expected concentration in 2010	382 ppmv					
Expected concentration in 2100	[500, 1000] [540, 970] [490, 1260] ppmv	[1570,3730] ppbv	[354, 460] ppbv			
Percentage rate of concentration change	0.4%/yr	0.6%/yr	0.25%/yr	0%/yr	5%/yr	2%/yr

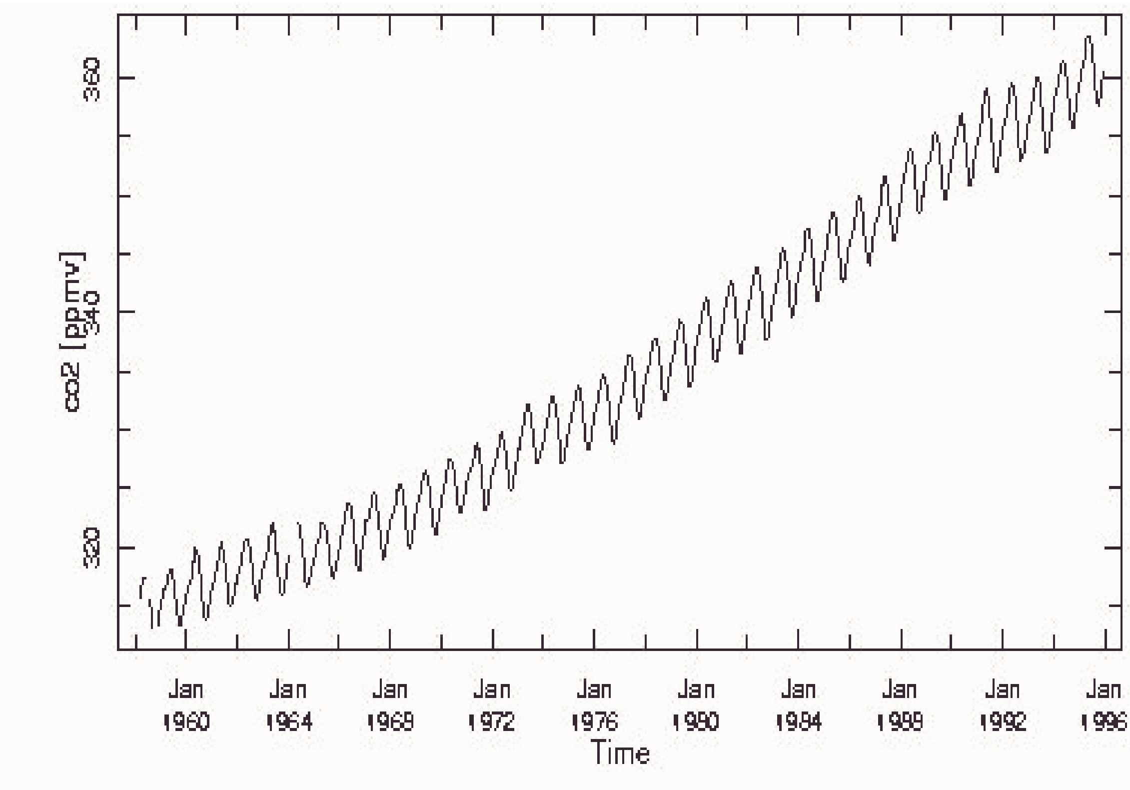

Figure 1: Increasing atmospheric CO_2 concentrations at Mauna Loa, Hawai.
Source: http://ingrid.1dgo.columbia.edu/SOURCES/.KEELING/.MAUNA-LOA.cdf/.co2/html+viewer?

Given this outlook, the Austrian Federal Government ratified the United Nations Framework Convention on Climate Change (UNFCCC) on 28 February 1994, which has the objective to achieve stabilization of greenhouse gas concentrations in the atmosphere that would prevent dangerous anthropogenic interference with the climate system (FMEYF, 1997). In addition, Austria committed itself to the Toronto Target, which calls for a national target of a 20% reduction of carbon dioxide emissions by 2005, based on the emissions of 1988. In this context, the Ministries of Science and Environment commissioned the studies 'System Analytical Assessment of the Carbon Balance in Austria — Carbon Balance for 1990 (Part I)' and 'Dynamical Modeling (Part II)', which were published by the Austrian Research Centers Seibersdorf (Orthofer, 1997; Jonas, 1997) in 1997. Although research-oriented, this study aims at providing relevant scientific knowledge allowing Austria to cope with the UNFCCC and related matters in an adequate fashion. Whereas Part I provides a detailed (sub-national) insight into the carbon flows for 1990, Part II deals with the crucial question of what may happen to the Austrian carbon balance in the future (1990–2050). As a result and in order to develop strategies for climate protection, the study stressed the need to not only consider emissions from fossil fuels, but also carbon flows into the atmosphere originating from the lithosphere (e.g., in the form of cement), from soils (loss of humus) and from the production chain (including foreign trade, consumption, disposal), as well as the removal of atmospheric carbon by Austria's terrestrial biosphere.

In the meantime, the Kyoto Protocol to the UNFCCC was adopted by the Third Conference of Parties in December 1997 (UNFCCC, 1998). The Kyoto Protocol not only contains legally binding commitments to limit or reduce greenhouse gas emissions (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6),[1] but also allows Annex I countries to account for net emissions from some terrestrial ecosystems[2] (cf., also IGBP, 1998). However, accounting for net emissions from terrestrial ecosystems causes many problems that may run counter to the aspired goals of the climate convention. If we consider, for example, the case of afforestation and reforestation being larger than deforestation, measured in terms of carbon stocks, then we may have a terrestrial carbon sink. This terrestrial carbon sink, however, is an important if only *temporary* sink and therefore not a permanent offset to fossil fuel emissions. Besides this general problem, we face the problem of not yet being able to assess the carbon reservoirs and flows of the terrestrial biosphere (including soils) very well, resulting in non-negligible uncertainties (see, in particular, Jonas *et al*., 1999b). Other problems resulting from the Protocol are, for example, that the Kyoto-compliant terrestrial sources and sinks of carbon are only a small subset of the terrestrial carbon budget and that a so-called "gross-net disparity"[3] may decrease the need for reductions in fossil fuel emissions. Because the Protocol is not based on Full Carbon Accounting (FCA), IGBP (1998) conclude further that this could actually lead to an increase of cumulative emissions.[4]

Having to cope with the challenge of integrating Kyoto-compliant terrestrial ecosystems in accounting for carbon emissions, which appears to be more a result of political rather than scientific deliberations (Bolin, 1998), the aforementioned study of the Austrian carbon balance (Jonas, 1997; Orthofer, 1997) receives broad attention.

There are, however, severe concerns whether the reduction of uncertainties that is required to accomplish Full Carbon Accounting for Austria can be achieved. Based on the first carbon balance results for Austria, Jonas *et al*. (1998) conclude that the

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[1] Together the OECD and Countries in Transition agreed on a decrease of greenhouse gas emissions of ~5% below 1990 levels until 2010 (Bolin, 1998). The observed trends for the period 1990–1995 are: Austria: -3%; the EU: -1%; OECD excluding the EU: +8%; Countries in Transition: -29%; and Non-Annex I parties: +25%.

[2] Article 3 (Nos. 3 and 4) states that (UNFCCC, 1998):

> *3. The net changes in greenhouse gas emissions from sources and removals by sink from direct human-induced land use change and forestry activities, limited to afforestation, reforestation, and deforestation since 1990, measured as verifiable changes in stocks… shall be used to meet the commitments under this Article of each Party included in Annex I.*
>
> *4. …each Party included in Annex I shall provide data… to establish its level of carbon stocks in 1990 and to enable an estimate to be made of its changes in carbon stocks in subsequent years.*

[3] The term "gross-net disparity" refers to the problem that 1990 estimates of carbon emissions, which form the baseline for all emission reduction targets of the Kyoto Protocol, exclude sinks related to terrestrial ecosystems. In contrast, sources and sinks from the Kyoto forests *are* to be counted as part of a country's efforts to reduce emissions within the specified commitment period (2008 to 2012) (IGBP, 1998).

[4] According to Jonas *et al*. (1999a), FCA follows, in a consistent fashion, the full carbon system concept and is a full carbon budget that encompasses and integrates all (carbon-related) components of all terrestrial ecosystems and is applied continuously in time (past, present, and future).

incomplete knowledge about biospheric processes and data may make it impossible to carry out calculations of net emissions. Therefore, these uncertainties can only be reduced if an attempt is made to generate, improve and/or complement basic data where possible. This is why, among other reasons, IIASA research focuses on how the Kyoto Protocol can be improved in this respect and is convinced that understanding the nature of terrestrial carbon sinks requires a Full System Carbon Budget.

Jonas *et al*. (1999a) provide a detailed insight into the issues of Full Carbon Accounting and the Kyoto Protocol, addressing the unresolved issue of the Protocol's legal basis of compliance, the scientific challenge of FCA, as well as the scientific challenge of establishing 1990 baselines and post-1990 baseline scenarios, and the scientific challenge of accounting for uncertainty. In this respect, the authors emphasize that the question of whether the uncertainties in estimating carbon flows associated with land-use change and forestry are so large as to threaten the compliance process, cannot yet be answered with sufficient rigor.

In January 1999, the proposal 'Austrian Carbon Balance Model (ACBM)' commenced, supported by the Austrian Research Centers Seibersdorf (ARCS), the Institute of Industrial Ecology (IIE) in St. Pölten, and the Joanneum Research Forschungsgesellschaft (JRG) in Graz (Orthofer *et al*., 2001). The aim of the study was to grasp and quantify the dynamics of Austria's Full Carbon System including the product chain, and to link carbon flows with political scenarios. The ACBM study goes a step further than the carbon balance model and the dynamical model of 1997, in terms of a more detailed modeling approach as well as assessing uncertainties, and beyond that, aims for application by having an instrument for policy implementation. In addition, more regional aspects will also be considered. A central goal of the ACBM study was to provide political decision-makers with the possibility of evaluating the effects of alternative policy options within a framework that reflects Austria's full carbon system. The study also aimed at providing an overall evaluation of the Austrian carbon flows, which can be seen as a prerequisite for drafting the third National Climate Report. Due to the large amount of expertise gained during the work on the carbon balance for 1990 and the dynamical model, the ACBM builds upon this knowledge. As this study was recently completed, we will come back to some of the results in the following sections.

IIASA investigates the possibility of carrying out research in support of Austria's carbon balance modeling activities in general, and as part of the ACBM project in particular. In the carbon balance for 1990, Orthofer (1997) employs a conceptual framework to estimate Austria's 1990 carbon flows [where relevant flows related to Austria's terrestrial biosphere are taken from Jonas (1997)]. In contrast, Jonas (1997) employs a consistent, physically based model to calculate Austria's 1990–2050 carbon flows. Based on the results of the conceptual framework, Orthofer (1997) states that one should be aware that his carbon flow calculations imply a substantial degree of inherent uncertainties, which are a direct result of missing knowledge about the functioning of the system and insufficient quantitative data about material and carbon flows, respectively. Furthermore, some basic data sets could not be directly used for analysis as — though consistent themselves — they at times contradicted other data sets. Nevertheless, both verification and crosschecks of the carbon balance for 1990 and the dynamical model were carried out, in a conceptual fashion by Orthofer (1997) and in a physical, quantified fashion Jonas (1997). For the ‘conceptual framework’ of the ACBM I Orthofer (1997) points out, that “...*it is useful for an overall assessment of the carbon system, but is limited in its ability to reflect the situation in a detailed level*.”

Thus, building on the outcomes of Jonas *et al*. (1998), the main challenge to improve the existing carbon balance, is a carbon consistent database that allows the substantial lowering of the degree of uncertainties of Austrian carbon flows as well as integrating these into the carbon accounting approaches that are necessary to cope with the requirements of the Kyoto Protocol. In conclusion, it is IIASA’s view that reducing uncertainties should go hand in hand with model refinement.

2 Objectives

The objectives of this study are to:

- improve the foundations for the Austrian carbon balance framework in general;
- reach consistency for some relevant carbon flows on a national level;
- track down carbon (C) inconsistencies; and
- discuss options on how these can be overcome.

Moreover, the range of uncertainties for several carbon flows will be calculated and reasoned in a first-order approach. The reference year for the study is 1990, which is the base year for energy-related emission reduction commitments underlying the Kyoto Protocol.

These tasks are part of a Carbon Consistent Database (CDB) for Austria, which will be completed in 2001 and will put Austria a step forward in Full and Partial Carbon Accounting (FCA and PCA) as envisaged by IIASA’s Forestry Project.

The objectives of the CDB are to:

1. Provide a consistent database to complement the ACBM.
2. Place Austria’s carbon balance modeling work into an international science and policy context with a focus on the UNFCCC.
3. Support Austria in fulfilling its carbon crediting obligations by:
    - providing an “Austrian consistency standard” that will allow Austrian institutions to check their highly detailed but regionally and/or sectorally confined databases against a less detailed but Austrian consistent database;
    - assigning uncertainties to Austria’s carbon budget; and
    - assisting Austria’s Federal Environment Agency to update and complete its emissions inventory, particularly with regard to Agriculture, Land-use Change and Forestry, and Waste (biogenic and non-biogenic, but carbon relevant).

3 The Austrian Carbon Balance Framework

3.1 Defining the System

In general, the term "system" is applied to classify parts in a holistic context. In material flow accounting studies, a system is defined by processes (the equivalent term in the Austrian carbon balance framework is modules), flows of goods, material flows and spatial as well as temporal limits (Baccini and Brunner, 1991; Baccini and Bader, 1996; Brunner *et al*., 1994). The spatial limits of the Austrian carbon framework, seen from IIASA's viewpoint, are represented horizontally by the Austrian borders and vertically by the top of the atmosphere (stratopause) as well as the upper lithosphere. Narrow time limits are assigned to the year 1990, broader time limits are fixed by the 3-year period from 1989 to 1991. In the latter case, mean values are calculated for this period. Where necessary, additional data referring to neighboring years may also be used but are then mentioned explicitly. The concept of the Austrian carbon balance system applied here builds upon that of Orthofer (1997). The kind and number of carbon flows considered in view of achieving a manageable level of complexity is mentioned in the following sections.

3.2 Top-down versus Bottom-up Approach

In order to find the best way for creating a basic structure for the carbon consistent database, several initial meetings were held with the builders of the ACBM. In particular, close cooperation evolved with IIE in St. Pölten, since IIASA initially concentrated work on the PRODUCT and WASTE modules. It turned out that there was a need for creating a common framework for integrating the different levels of handling carbon flows by the different research groups. For example, at the time of starting work on this study, IIE was working on a very detailed level running beyond the extent of IIASA's intention of a carbon consistent database. In the first run, IIASA created flow charts for different levels of complexity, aiming at reducing complexity towards a level that could be made consistent with given limits of resources.[5] The reason for not talking about the "common" ACBM structure is because that structure was not explicitly discussed when IIASA joined the ACBM core group in June 1999. Hence, for building the database, IIASA built a carbon balance framework following an integrated top-down approach to various levels of detail.

As an example, *Figure A1* in the Appendix illustrates the most complex level of the product module handled by the IIE. For convenience, we call this very detailed level of complexity Level 3. The same level of complexity is also drawn in *Figure A2* in the Appendix for the waste module. Starting from this very detailed approach, complexity was reduced by integrating sub-modules depending upon their relevance on carbon flows.

[5] For comparison, the structure of the carbon balance for 1990 and the dynamical model was built on a trade-off between the level of detail, consistency, data manageability, system clearness and questions of interpretation (Jonas, 1997; Orthofer, 1997).

Consequently, this level of complexity is called Level 2. *Figures A3* and *A4* in the Appendix give a clear picture of the reduced extent of complexity.[6]

A further reduction of complexity leads to the so-called Level 1, which is the level on which all modules (ATMOSPHERE, AGRICULTURE, FORESTRY, ENERGY, PRODUCTION, WASTE, IMPORT/EXPORT, HYDROSPHERE and LITHOSPHERE) are directly linked together via relevant carbon flows. *Figure 2* illustrates this Austrian carbon balance framework, emphasizing the PRODUCT and WASTE modules. The framework reflects IIASA's viewpoint but is agreed upon by members of the IIE.

3.3 Adding Top-down Knowledge

In order to obtain a synopsis of relevant carbon flows on a national level, and from that to deduce the priority fields for work on consistency, it was decided to add existing quantitative data on carbon flows to IIASA's Austrian carbon balance framework. Therefore, values of carbon flows derived from the 1990 carbon balance study, which are taken from Orthofer (1997) but are partly grounded on the dynamical modeling by Jonas (1997), have been used as a starting point. As an example, *Table 2* shows the carbon flows in the PRODUCT module by demonstrating the order of magnitude. *Tables A1–A4* in the Appendix completes this list for the other modules, also taken from Orthofer (1997). Internal carbon flows of individual modules are not considered at this level of complexity and are only quoted for completeness. As can be seen from *Tables 2* and *A1–A4* in the Appendix, inputs and outputs of individual modules are not balanced, indicating potential inconsistencies or carbon storage, respectively.

The whole picture (from the perspective of the PRODUCT and WASTE modules) is drawn in *Figure 3* for all relevant carbon flows in the Austrian carbon balance framework on Level 1. The carbon flows into and from the ENERGY, AGRO and FORESTRY modules are dominating the Austrian carbon balance. The import and export of carbon via capital and consumer goods are also very important and dominate the carbon flows in the PRODUCT module eminently. The residual carbon flows are comparatively small.

To focus on the balance of the AGRO and the FORESTRY modules is essential since the Kyoto Protocol allows for the accounting of net emissions from some Kyoto compliant terrestrial ecosystems. As discussed previously, the partial inclusion of terrestrial ecosystems may result in an increase of net carbon emissions. Therefore, a glance at present knowledge of the total emitted and sequestered carbon of terrestrial ecosystems highlights the underlying scientific challenge.

[6] At the time of writing, two different flow charts for the product module Level 2 were still under discussion. Differences rest on the number of sub-modules, the number of flows as well as on criteria to aggregate carbon flows.

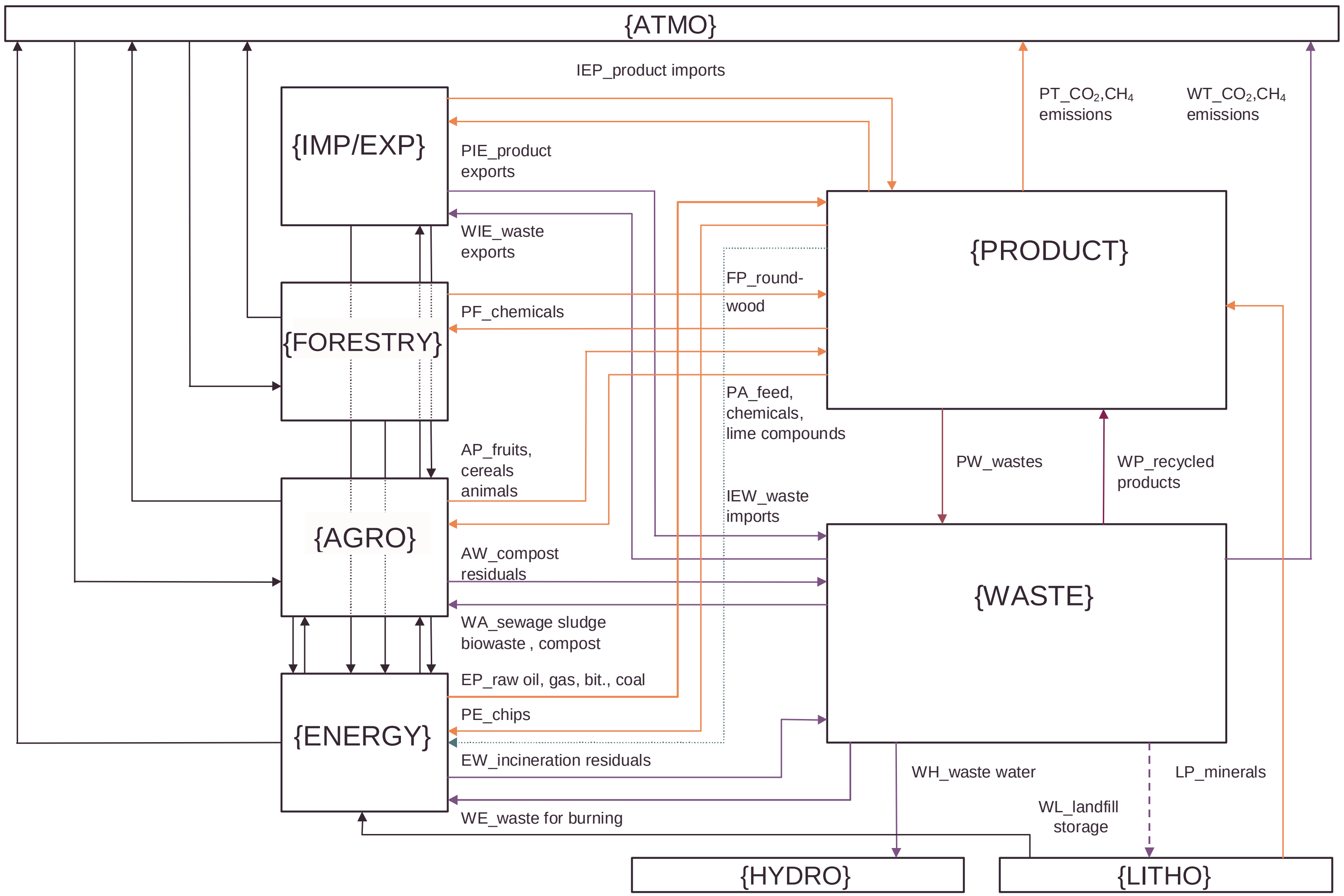

Figure 2: Flow chart of Level 1. Sources: IIASA, IIE.

Table 2: Carbon flows into and out of the PRODUCT module.
Source: Orthofer (1997).

PRODUCT MODULE			**(mio. t C/a)**
COMPOSITE CARBON FLOWS[a]	**INDIVIDUAL CARBON FLOWS IN THE 1990 CARBON BALANCE FRAMEWORK**		
IN:			
AP_fruits, cereals, animals		**1.8**	
	From Food to Products		0.6
	From Food to Raw materials		0.7
	From Raw materials to Raw materials		0.5
FP_roundwood		**2.1**	
	From Roundwood to Products		0.0
	From Roundwood to Raw materials		2.1
XP_product imports		**4.8**	
	From Fertilizer to Fertilizer		0.0
	From Food products to Food products		0.2
	From Products to Products		0.5
	From Raw materials to Raw materials		4.1
EP_raw oil, gas, bitumen, coal		**1.0**	
	From Non-energetic use to Products		0.2
	From Non-energetic use to Raw materials		0.8
LP_minerals		**0.7**	
	From Minerals to Products		0.0
	From Minerals to Raw materials		0.7
WP_recycled products		**0.0**	
	From Recycling to Raw materials		0.0
OUT:			
PA_feed, chemicals, lime compounds		**0.0**	
	From Fertilizer to Litter-humus-soil/fields		0.0
PX_product exports		**4.7**	
	From Fertilizer to Fertilizer		0.0
	From Food products to Food products		0.1
	From Products to Products		0.2
	From Raw materials to Raw materials		4.4
PT_CO2,CH4 emissions		**1.8**	
	From Human nutrition		0.3
	From Production		0.8
	From Short-lived products		0.7
PW_wastes		**3.3**	
	From Food products to Waste active		0.2
	From Human nutrition to Waste active		0.3
	From Long-lived products to Waste inert		0.5
	From Long-lived products to Waste active		1.1
	From Production to Waste active		0.3
	From Raw materials to Waste active		0.0
	From Short-lived products to Waste active		0.9
Sum input			**10.4**
Sum output			**9.8**
Balance			**0.6**

[a] The notation of individual carbon flows is to some extent different to those employed by Orthofer (1997).

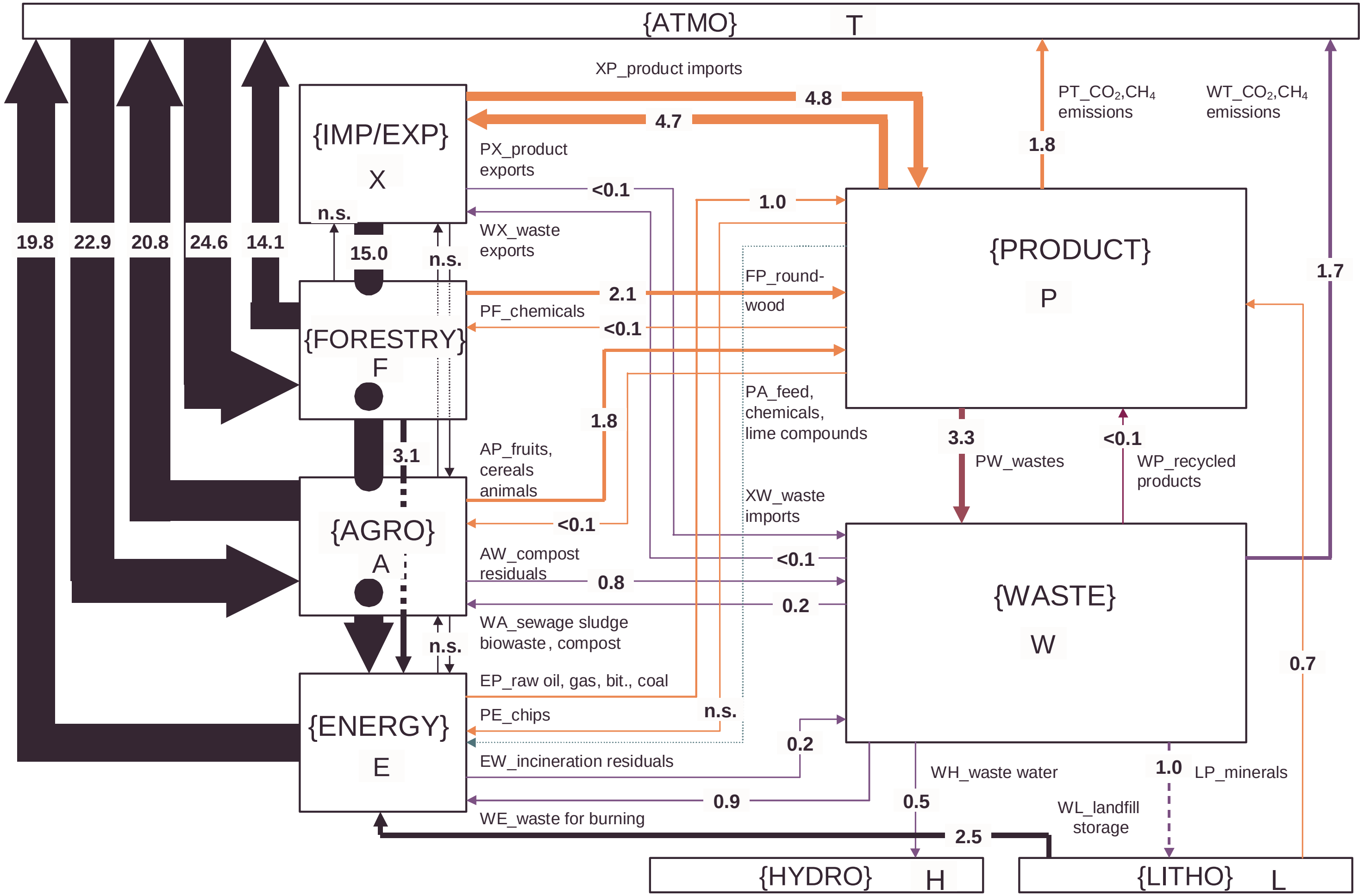

Figure 3: Relevant carbon flows in the ACBM II framework, indicated by thickness of arrows and figures. Accounting unit is mio. t C/a. Sources: IIASA, IIE, Orthofer (1997).

The input of carbon from the ATMOSPHERE to the AGRO module [22.9 mio. t C/a (Jonas, 1997; Orthofer, 1997)] and the output of carbon from the AGRO module to the ATMOSPHERE [21.5 mio. t C/a (Jonas, 1997), 20.8 mio. t C/a (Orthofer, 1997)] seem to be quite balanced. From these figures, one could be tempted to conclude that Austria's agriculture, on the whole, is acting as a carbon sink (outflows from the atmosphere are greater than inflows). However, according to Jonas (1997), this would be a misinterpretation because considerable carbon flows also take place in the *lateral* direction, that is, to and from the PRODUCT and WASTE modules, at the expense of Austria's soil carbon pools. For example, Dersch and Böhm (1997) report a long-term mean loss rate of -0.24 t C/ha/a for arable land, which, in consequence, resulted in $329*10^3$ t C/a losses from soil humus in Austria in 1990 (Jonas, 1997). Therefore, Austria's soil carbon pools do not receive the amount of carbon they actually should, with the consequence that their mineralization flows are adversely balanced.

In the case of the FORESTRY module, an input of 24.6 mio. t C/a is confronted with an output of 14.1 mio. t C/a. One explanation for this is the enormous amount of carbon sequestered by the increase of the growing stock in Austrian woods. Orthofer (1997) reports the amount of annual carbon storage to be approximately 5.4 mio. t C/a. In contrast, a CO_2 sink strength of 3.6 mio. t C/a has been assessed in Austria's Second National Climate Report (FMEYF, 1997), and a revised sink strength of 4.5 (±1.448) mio. t C/a was published by Jonas (1997).[7] Differences between the figures rest on the consideration of Austria's total forest (Orthofer, 1997) or exploitable forest (FMEYF, 1997; Jonas, 1997), respectively. Also, Orthofer (1997) had to change the original carbon flows taken from Jonas (1997) adapting it to other requirements of wood harvest statistics. The second explanation for the unbalanced carbon flows between the FORESTRY and the ATMOSPHERE module is the amount of harvested carbon. The differing numbers stress the need for reducing uncertainty of carbon accounting.

In comparison, carbon emissions from the energy system in 1990 were about 20.5 mio. t C/a, according to Jonas (1997).

In conclusion, *Figure 3* together with *Tables 2* and *A1–A4* in the Appendix, serve as the starting point to determine where main endeavors should be undertaken in reducing the uncertainty of Austria's relevant carbon flows. The selection criteria include the size of carbon flows as well as present knowledge on data quality.

The relevant carbon flows, in addition to Austria's carbon emissions from its energy system, are:

- Carbon flows into and from the FORESTRY module;
- Carbon flows into and from the AGRO module;
- Carbon flows referring to the imports and exports of investment and consumer goods;
- Carbon flows from the PRODUCT to the WASTE module; and
- Carbon emissions of the PRODUCT and WASTE modules.

[7] The difference between the values reported by FMEYF (1997) and Jonas (1997) is mainly due to the use of different conversion factors applied for converting 1 m^3 o.b. usable stem wood into 0.28 t C (FMEYF, 1997) and 0.36 t C (Jonas, 1997) total tree biomass, respectively.

4 General Approach in Building a Carbon Consistent Database

The general procedure in building a carbon consistent database, resting upon the principles “logic build”, “complete” and “without contradiction”, is described in this section. In order to achieve a consistent carbon balance framework, we consider six items to be essential:

- Combined top-down and bottom-up approach;
- Determination of material flow range;
- Determination of conversion factor range;
- Application of (improved) emission factors;
- Calculation of uncertainties; and
- Balancing the modules.[8]

In the time between beginning this study (May 1999) and its final completion, the Intergovernmental Panel on Climate Change (IPCC) published the report “Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories” (IPCC, 2000), which also addresses some of these issues in great detail, but is nevertheless limited on the anthropogenic side of the carbon cycle (see below).

The following paragraphs therefore mainly reflect the status of discussion at IIASA before the publication of the IPCC good practice guide and also serve to introduce the authors’ concept of the consistency of carbon flows. To be comprehensive and self-reflecting, some essential remarks are included from the IPCC report.

4.1 Simultaneous Top-down and Bottom-up Approach

Based on the results of the 1990 carbon balance (Orthofer, 1997), the dynamical model study (Jonas, 1997), and on discussions with IIE, IIASA pursues a top-down and bottom-up approach in parallel. The reasoning behind this is because proceeding merely from bottom-up (irrespective of whether or not in a detailed or less detailed intra-module fashion) may/will not be consistent with an inter-module top-down carbon flow approach. It must be expected that any intra-module bottom-up flow concept will require flow corrections in order to match an inter-module top-down flow concept. Only the parallel consideration and realization of the two approaches will result in a C consistent inter/intra-module flow concept. By proceeding in this way, it is certain that the boundary condition of “C consistency”, step-by-step from a very low resolved level (national level or Level 1) to a highly detailed level (Level 3), will be preserved. This approach will result in statements on the minimum and maximum values of carbon flows and will, therefore, provide grounds for consistent balancing of the framework. Proceeding in this way offers the opportunity of crosschecking aggregated carbon flows as well as single modules of ACBM II.

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[8] Other authors, e.g., Baccini and Bader (1996) or Brunner *et al.* (1994) use the equivalent term “process”, which is defined by the transformation, transport or storage of goods and materials. Examples for processes are: incineration plants, cars, cities, households, and business lines. IIASA applies the term “modules” in accordance with the builders of the ACBM.

We find our simultaneous top-down and bottom-up approach confirmed by the IPCC (2000) who, in the context of quality assurance and quality control of greenhouse gas emission inventories, recommends order-of-magnitude checks by using a top-down or a bottom-up approach. For the example of N_2O emissions, the IPCC illustrates that if N_2O estimates for nitric acid production were determined using a bottom-up approach (i.e., emission estimates were determined for each individual production plant based on plant-specific data), the emission check would consist of comparing the sum of the individual plant-level emissions to a top-down emission estimate based on national nitric acid production figures and IPCC default Tier 1 factors.

4.2 Determination of Material Flow Range

Due to its comprehensive character FCA consistency requires, to a certain extent, material flow consistency as a prerequisite. Therefore, satisfying the underlying material flow consistency is considered crucial in carrying out an FCA approach for Austria or any other country or entity. For example, an assessment of carbon flows in plastics requires knowledge on the amount of plastic flows. Another example is wood related carbon flows, which can only be assessed by knowing the supply and demand of wood. Creating a framework of consistent material flows on a regional or national level is a challenge in itself (cf., e.g., Baccini and Bader, 1996; Brunner *et al*., 1994; Dörflinger *et al*., 1995; Haberl, 1995; Hüttler *et al*., 1996; Kaas *et al*., 1994; Körner *et al*., 1993; Punz *et al*., 1996; Schulz, 1999; Steurer, 1994) and is therefore a bottleneck for the FCA approach.

4.3 Determination of Conversion Factor Range

Several conversion factors are usually required to assess the carbon concentration of different materials taken into account by FCA. It should be noted, however, that based on existing knowledge, conversion factors may vary widely and are by far not available for all materials. Reducing uncertainty in this regard means determining the consistent carbon conversion factors. Additionally, a combination of several conversion factors is needed in many cases to calculate the carbon contents of different materials. For example, if we consider the carbon contents of wood we have to deal with volume data (with/without bark), moisture content, dry and wet density, and of course, carbon contents. Thus, the application of plausible conversion factors is of particular importance for the carbon consistent database.

4.4 Application of (Improved) Emission Factors

In addition to the assessment of material based carbon flows, the application of emission factors is the most usual procedure in PCA (cf., e.g., IPCC, 1995; 1996a,b; 1997a,b,c) and is therefore also of particular importance for FCA. The reduction of uncertainties underlying emission factors is an indispensable goal but of course heavily dependent on specific research work conducted in this area.

4.5 Calculation of Uncertainties

Whenever statements on the amount of carbon (or material) flows are made, it is essential to also add information on the underlying uncertainties. This is usually done by certain statistical measures. However, it is clear that this is not always possible due to the lack of appropriate data. To our knowledge, at the time of starting work on the Austrian carbon consistent database, no definition of the term *uncertainty* existed within the carbon community that could be applied to *quantify the lack of knowledge*. In general, there are two types of knowledge, sometimes referred to as *soft* (tacit) and *hard* (explicit) knowledge. Soft knowledge is gained through experience and application of context and resides within an individual or organization. Polanyi (1966) defined soft knowledge as “knowing more than we can tell”, and viewed this knowledge as largely inarticulable. In order to be complete, we include soft knowledge within our consideration of uncertainty.

On the other hand, hard knowledge can be expressed formally and systematically. It is knowledge that can be expressed in words, numbers, formulas, procedures, and universal principles and, at the same time, can be easily communicated. It is gained through codifying previously experienced and applied information into understandable symbolizations of tacit knowledge. Most importantly, hard knowledge or lack of it can be quantified.

The uncertainty range (determined either by soft or hard knowledge) of carbon flows is crucial for meeting consistency requirements. Let us, for example, consider two or more given data sources, which all provide figures to a certain material or carbon flow, but refer either to the origin of the flow (supply side) or the destination of the flow (demand side). The production and consumption of goods or wood could be examples. Then, the question to answer is under which conditions (at least minimum) consistency requirements are met. *Figures 4* and *5* demonstrate two cases, which could occur in dealing with different uncertainty intervals of the origin and destination of carbon flows, respectively.

In *Figure 4*, neither average carbon flows fall into the uncertainty interval of the opposite carbon flow, nor do the uncertainty intervals overlap with each other. This indicates a clear case of inconsistent data sources. In order to overcome the underlying problems, further assumptions must be made. In *Figure 5*, at least the uncertainty intervals overlap, which leads to the conclusion that carbon flows can potentially be made consistent. Hence, for IIASA’s consistency concept, the size of the uncertainty band is essential for meeting consistency.

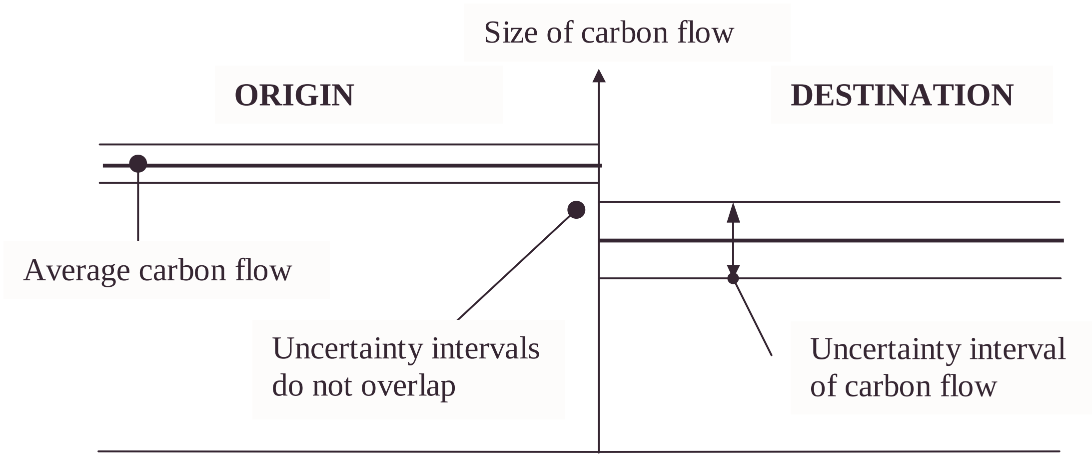

Figure 4: Inconsistency between the origin and destination of carbon flows. Source: IIASA.

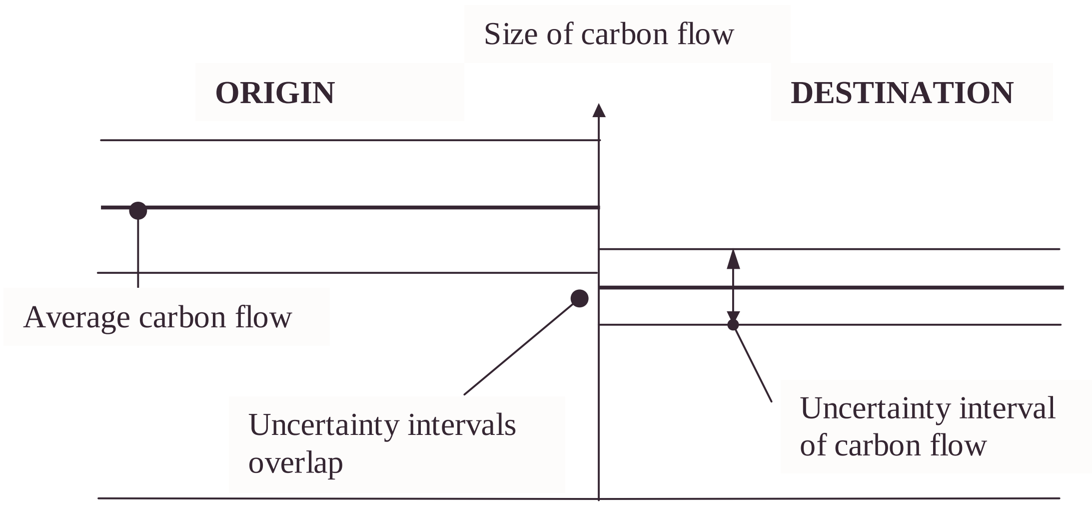

Figure 5: Consistency between the origin and destination of carbon flows. Source: IIASA.

4.5.1 Statistical treatment of uncertainties (hard knowledge)

Until now, only a minority of material and (full) carbon accounting studies seek to quantify uncertainty by *hard* knowledge, that is, statistics in particular. Hence, in the following paragraphs, only very basic statistical methods are discussed, which are considered to quantify uncertainty intervals in this study.

The simplest and easiest way to statistically describe dispersion of a given data set is the use of the statistical measure *range*. The range of a statistical distribution or random variable X is b – a, where [a, b] is the support of X. The range of an ordered set of data is $x_{(1)}$ * $x_{(2)}$ * … * $x_{(n)}$ is $w = x_{(n)} - x_{(1)}$ (Kotz and Johnson, 1986). The range gives depletive information on the sample, if only two values exist. However, increasing the sample size leads to increasing knowledge about dispersion and therefore range, as a measure of dispersion, becomes increasingly inapplicable. This is because only extreme values are considered and nothing can be said about the site of medium elements. Thus, range is preferably used for small samples with $n < 13$ (Sachs, 1999). Several methods exist to assess standard deviation on the basis of a given range (Sachs, 1999). Different ranges can only be compared if they are based on the same number of sample characteristics (Schulze, 1990).

In the case of a sufficient sample size, the statistical measures *frequency distribution*, *standard error*, and *standard deviation*, together with *confidence interval* may be considered. As IPCC (2000) points out, the two statistical concepts of the probability density function and confidence limits, derived from measurements and expert knowledge, are the main instruments to obtain the best available estimates in a pragmatic approach to producing quantitative uncertainty estimates. Therefore, describing and defining the best available probability density function for each of the individual carbon flows is of prime importance.

Nevertheless, considering our knowledge on available data on material and carbon flows as well as conversion factors, it is essential to emphasize that large sample sizes are at one's disposal only in minor cases. Since we do not have samples larger than $n > 13$, we only apply the statistical measure range as a first-order approach in this study.

A common way to overcome the obstacle of a missing probability density function is to assume a normal distribution (see also, IPCC, 2000). For the final version of the Austrian carbon consistent database, this approach is applied and discussed in detail by Jonas (2001). Although the uncertainty band may be belittled by assuming specific probability functions, they still rest on so-called tacit knowledge.

4.5.2 Error propagation

Calculating the carbon contents on the basis of wood flows, for example, requires the manifold multiplication of material flows and conversion factors, each characterized by a significant uncertainty interval. This necessitates applying the law of error propagation. The simplest way to calculate the new uncertainty interval is by multiplying maximum as well as minimum values and then calculating the resulting average (Sachs, 1999). This approach is applied in this study.

If the average values and the standard errors are known and we want to know the resulting standard error by multiplying conversion factors, more complex calculations must be applied (Sachs, 1999). As an example, in the case of Full Nitrogen Accounting Kaas *et al*. (1994) apply calculations of this kind to grasp the uncertainty interval of regional nitrogen flows. The authors thereby assume a normal distribution of density and nitrogen contents. As another example, Baccini and Bader (1996) elaborate the problem of error propagation in material flow analysis not only for a stationary but also for a dynamic case. The IPCC (2000) lists two convenient rules for combining uncorrelated uncertainties and discusses the application of the Monte Carlo analysis for correlated uncertainties in detail.

In general, methods to communicate uncertainty must be practical, scientifically defensible and robust enough to be applicable to a range of source categories, methods, and national circumstances (IPCC, 2000).

The IPCC therefore considers the ideal information for estimating uncertainties in greenhouse gas inventories to include:

- The arithmetic mean of the data set;
- The standard deviation of the data set (the square root of the variance);
- The standard deviation of the mean (the standard error of the mean);
- The probability distribution of the data; and
- Covariances of the input quantity with other input quantities used in the inventory calculations.

In summary, we must deal with soft as well as hard knowledge to get a feeling for the uncertainties underlying the Austrian carbon flows. In this study, to express uncertainty by hard knowledge, we favor the simplest statistical measure range due to the lack of sufficient data required for applying more declarative measures. Soft knowledge uncertainty will be described verbally. As a consequence, uncertainties are calculated by combining uncertainties of different data with each other, which results in an overall uncertainty of distinct carbon flows. As already mentioned, a more complex approach is applied by Jonas (2001) for the final version of the Austrian carbon balance database.

4.6 Balancing the Modules

Balancing the modules follows the *continuity equation*, which arises from the basic law of conservation of mass and states, matter that can be neither created nor destroyed. The equation also states that the net carbon flow from a reservoir must be balanced with the temporal change in the reservoir’s carbon content (Jonas *et al*., 1999a).[9]

One of the main advantages of FCA is the possibility of balancing modules in a model context. This provides the option of accounting for even unknown carbon flows or, equally important, accounting for the net change of carbon stocks. Balancing may also be helpful in supplying the database with explanations on the occurrence of inconsistencies and how they can be overcome.

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[9] See, Jonas *et al*. (1999a) for further information on the physical basis of FCA.

According to the aforementioned sections, we first intended to try balancing modules on Level 1 of the Austrian carbon balance, and meeting consistency for this less detailed level of complexity. Proceeding this way is seen to be a prerequisite for meeting consistency on more detailed levels (Levels 2 and 3), where the same requirements have then to be met again.

5 Carbon Flows on Level 1

Building upon the general procedure to create a carbon consistent database, the next step is to apply this procedure to establish consistent carbon flows on Level 1. Since Jonas (1997) points at considerable inconsistencies regarding fuelwood supply in the energy statistical data of the Austrian Institute of Economic Research — AIER — (AIER, 1996) and the wood balance statistical data of the Austrian Central Statistical Office (ACSO)[10] (Bittermann and Gerhold, 1995), and because carbon flows in the forestry sector are of major importance to the Austrian carbon balance, consistent wood related carbon flows are aimed at first. This task requires a great deal of effort and thus represents the limits of the work during the YSSP stay. The experience gained may serve as a guideline for the whole carbon consistent database.

5.1 Consistency of Wood Related Carbon Flows

In our carbon balance framework, the FORESTRY module is balanced by the carbon flows TF_net primary production, FT_emissions, FE_fuelwood, FX_fuelwood, FP_roundwood, PF_chemicals, FL_lithosphere, and LF_uptake.[11] *Figure 6* indicates these flows in the ACBM framework. The flows of carbon between the FORESTRY and the LITHOSPHERE modules have been reported to be zero (Orthofer, 1997), and are therefore neglected in the first run. To obtain consistency for the carbon flows FP_roundwood, FE_fuelwood and FX_fuelwood, it is crucial to also consider the wood flows of XE_fuelwood, XP_wood imports and PX_wood exports. According to our six-step approach in building a carbon consistent database only the simultaneous consideration of all relevant wood flows allows for crosschecking the individual flows and for balancing the underlying carbon flows.

Present knowledge on the amount of wood related carbon flows taken from the 1990 carbon balance and the dynamical model (Orthofer, 1997; Jonas, 1997) is depicted in *Tables 2* and *A1–A4* in the Appendix as well as in *Figure 6*, where the size of carbon flows is indicated by the thickness of the arrows.

[10] Now called Statistics Austria.
[11] The nomenclature indicates module of origin (first capital letter), module of destination (second capital letter) and the kind of carbon flow whereby, for convenience, a very simplified and short description is used for the latter. The nomenclature is essentially identical with the one used by the ACBM core group, but may be slightly different due to the provisional character of the ACBM II core group's nomenclature at the time of writing.

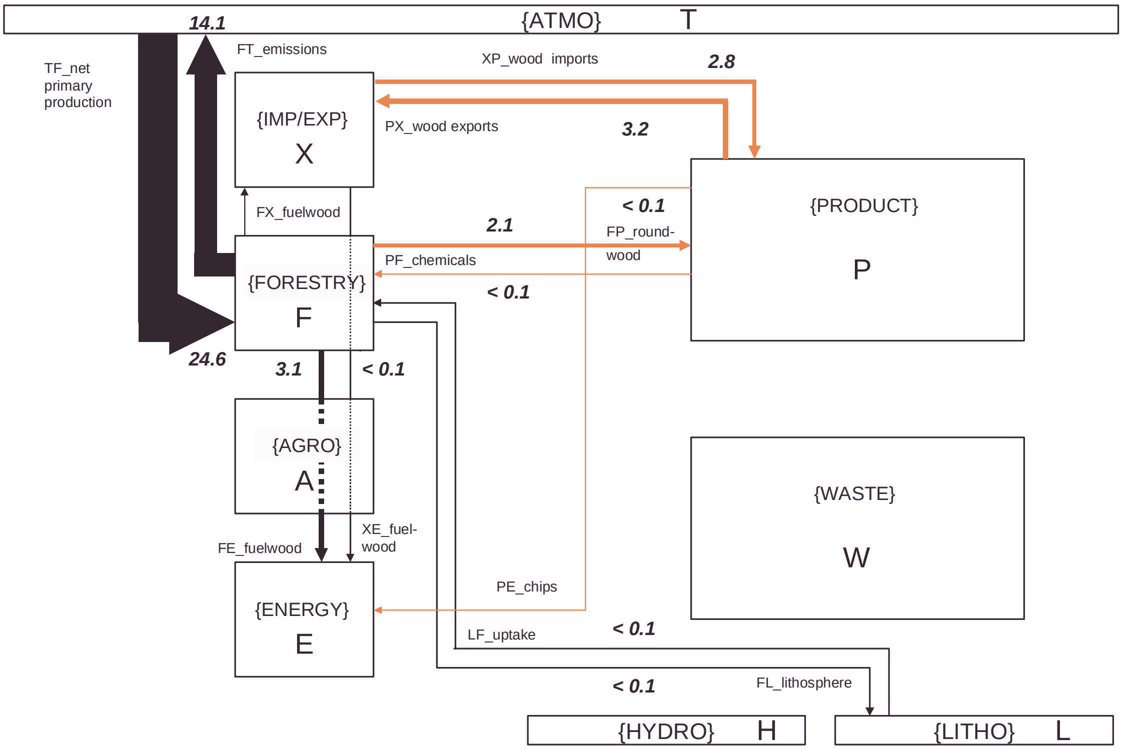

Figure 6: Carbon flows balancing the FORESTRY module and the import/export of wood products, indicated by the thickness of arrows and figures. The accounting unit is mio. t C/a. Sources: IIASA, Orthofer (1997).

5.1.1 Determination of wood flow range

As can be seen from *Figure 6*, the uptake of carbon by net primary production and the release of carbon from respiration processes are by far dominating the wood related carbon flows. Carbon sequestration and carbon export by wood harvest complete the balance of the module. (All other flows are negligible in the first run.) As we know about inconsistencies of wood harvest and fuelwood flows from Jonas (1997), we start dealing with carbon flows originating in the forests and entering into the PRODUCT, ENERGY and IMP/EXP modules.

5.1.2 Uncertainty of the Austrian wood harvest: Wood flows FP_roundwood, FE_fuelwood, FX_fuelwood

5.1.2.1 Harvesting Statistics (Holzeinschlagsnachweis)

In Austria, wood harvest is reported by different official statistical data sources. The first is the so-called Harvesting Statistics (*Holzeinschlagsnachweis* — HEN), an annually updated survey conducted by the Austrian Federal Ministry of Agriculture and Forestry (cf., e.g., FMAF, 1991 for the base year 1990). The HEN only reports about the supply of *Derbholz* (diameter > 7 cm) from forest soils, leaving wood with a diameter below 7 cm unconsidered. Wood from non-forest soils is also not included, as well as there is some underestimation of harvest in small-sized forest (private owners)

(*Kleinwald)*,[12] in which wood harvest is reported by sampling techniques (see also, *Table 3*). In general, the HEN records only actual sold wood at the end of the year as well as wood going into self-consumption. Uncertainties are not covered by the HEN. Although the formal reporting unit of *Derbholz per se* is m³ o.b. (over bark) (FMAF, 1995), the HEN is generally reported in m³ u.b. (under bark) units.

5.1.2.2 Austrian forest (wood)[13] inventory

The Austrian forest inventory (AFI) aims at assessing the quantity and quality of Austrian forests. The main quantified parameters are standing stock, increment, and exploitation. The AFI is based on a two-step sampling technique, with a net amount of 5,582 sampling sites at a distance of 3.89 km spread all over Austria, thereby considering trees beyond a DBH (diameter at breast height, i.e., 1.3 m above ground) of 5 cm (Schieler *et al*., 1996). Results represent estimated values, characterized with sampling error. Per hectare (ha) values are gained by using projection factors, which are derived from the relation of actually sampled areas to the total area of Austria (or to Austrian provinces, respectively). The mass of so-called “sampling stems” is assessed by using form functions (*Formzahlfunktionen*), and results are used to calculate per ha-based and total values. Due to methodological changes, the comparison of 1986/90 values with previous ones is problematic. On the one hand, the survey interval of forest inventories was shortened from 10 to 5 years in 1970/71, and on the other, Austria’s forest inventories refer to time-independent survey grids only since the last two inventory periods. Therefore, a comparison with earlier data is not always possible without difficulties.

In the AFI, the term *Nutzung* (exploitation) is employed, which refers to all non-standing stems irrespective of whether or not they are removed from the forest (Schieler *et al*., 1996). Therefore, forest inventory also considers felled wood, which is not exported from the forest, as well as harvest losses. Schieler *et al*. (1996) emphasize that it is inherent to the forest inventory that exploitation has to be larger than the fellings reported by other statistics.

5.1.2.3 Austrian wood balance

The most comprehensive data collection and assessment approach with regard to wood harvest is the wood balance (*Holzbilanz*) of Austria, which has been conducted for specific years since 1955. The penultimate revision includes data until the year 1978 (Österreichisches Holzforschungsinstitut, 1981), whereas a newly-arranged approach, using additional data sources like the micro census of fuel consumption as well as improved and extended conversion factors, is annually updated by Mag. Wakolbinger from the Austrian Federal Forest Agency and ACSO (Bittermann and Gerhold, 1995). Although comprehensive and consistent, the current Austrian wood balance is not faultless and will be subject to future amendments and improvements (Bittermann,

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[12] *Kleinwald* is a classification term concerning property rights of forest enterprises, applied by forest inventory (*Waldinventur)* (cf. e.g., Schieler *et al*., 1996) and refers to all enterprises with a size below 200 hectares (ha). Bittermann and Gerhold (1995) assess the underestimation to be 1 million festmeter (m³ u.b.) annually (for a total area of 2.1 million ha). This equals an underestimation of 0.48 m³ u.b./ha.

[13] The term “forest inventory” has been used for all former inventories including the 1986/1990 inventory. As of the 1991/96 inventory, the term “wood inventory” is used to emphasize the increased accentuation of ecological aspects (Schieler *et al*., 1996).

1999).[14] The supply side of the wood balance is basically built upon the HEN, but takes substantially more possible and suspected domestic wood sources into account.[15] All wood flows are counted in or converted to m^3 u.b., respectively, thereby constantly using revised and upgraded conversion factors (Bittermann and Gerhold, 1995).

5.1.2.4 Wood harvest in comparison

Table 3 illustrates wood harvest reported by forest inventory, the HEN and wood balance in comparison. The m^3 u.b. values have been converted to m^3 o.b. values and *vice versa*, by applying a first-order approach the conversion factor of 1.25 or 0.8 respectively, which has been used for the dynamical model by Jonas (1997).

Table 3: Officially reported wood harvest in Austria for the base year 1990 according to different data sources.

Source	**Characteristics/ deficits**	**Unit**	**Size**	**Updating interval (yr)**	**Mode of investigation**
HEN[a]	Diameter of wood above 7 cm; underestimation of harvest in small-sized forest (private owners) (approximately 1 mio. m^3 u.b.);[b] no consideration of wood from non-forest soils.	mio. m^3 u.b. mio. m^3 u.b.	*1990* **15.711** *Mean 1989–91* **13.675**	1	Declaration by wood owners.
AFI (1986/90)[c]	Exclusive consideration of exploitable forests; inclusion of all non-standing stems and natural losses.	mio. m^3 o.b. mio. m^3 u.b.[d]	Mean 1986–90 ***19.846*** *Mean 1986–90* **15.877**	5	Two step sampling technique.
Wood balance[e]	Total wood from forest areas, also including wood from non-forest areas,[f] bark.	mio. m^3 u.b. mio. m^3 u.b.	*1990* **22.212** *Mean 1989–91* **20.088**	1	Calculations based on HEN and AFI.

[a] FMAF (1991).
[b] According to Bittermann and Gerhold (1995).
[c] Schieler *et al.* (1996).
[d] Applying a conversion factor of 0.8, according to Jonas and Schidler (1996) and Jonas (1997).
[e] Bittermann and Gerhold (1995). The term "wood of non-forest areas" is in the order of 5–35% of the HEN and is not correlated with it.
[f] For example, wood from parks, fruit trees and agricultural land (Bittermann and Gerhold 1995). According to the Forestry Act of 1975 (§1, Abs. 5), non-wood areas are: biomass cultures for energy use (594 ha), forestry gardens (714 ha), forestry seed plantations (87 ha), christmas tree cultures (930 ha) and cultivation of walnut and sweet chestnut (4 ha). Therefore, the amount of non-wood areas is by far smaller than the amount of non-forest areas!

[14] In the meantime, framework conditions have changed so that a complete wood balance will very probably no longer be available in the future (Weiss *et al.*, 2000).
[15] These are partially deduced from knowledge on the demand side of wood.

Comparing the three different data sources shows the amount of harvested wood increasing from HEN to wood inventory to wood balance (*Table 3*). For 1990, HEN reports wood harvest to be 15.711 mio. m^3 u.b., whereas the mean wood harvest for the period 1989–1991 equals the substantial lower value of 13.675 mio. m^3 u.b. A large amount of storm damage occurred in 1990 and, as a consequence, led to an exceptionally high level of harvest. However, the five-year mean value of exploitation (*Nutzung)* in the Austrian wood inventory is 19.846 ± 0.707 mio. m^3 o.b., constituting almost two-thirds of the 1986/90 total annual increment of the Austrian exploitable forests (31.416 ± 0.552 mio. m^3 o.b.). Applying the above-mentioned conversion factor of 0.8 results in 15.877 mio. m^3 u.b. wood harvest. Finally, the Austrian wood balance estimates the harvest to be 20.721 mio. m^3 u.b. in 1990 or 18.635 mio. m^3 u.b. for the period 1989–91, respectively. The differences are shown in *Figure 7*.

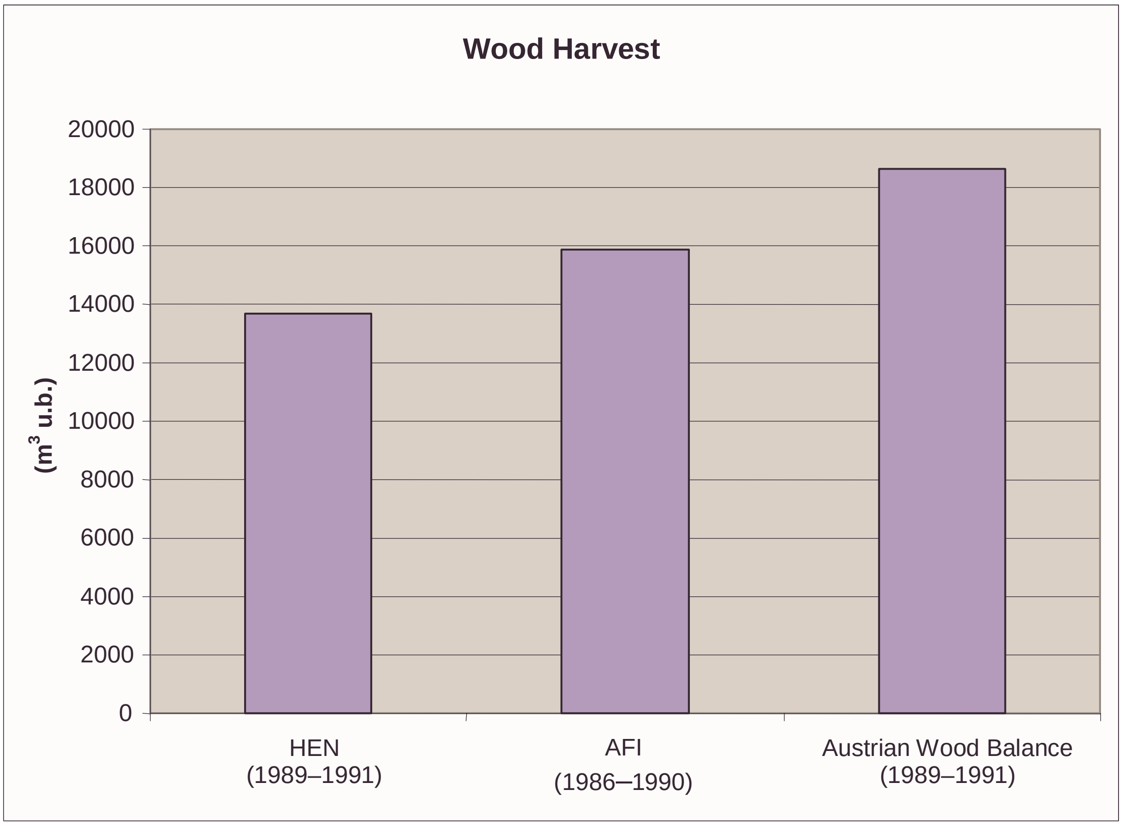

Figure 7: Varieties in wood harvest according to different reporting systems. The m^3 u.b. values of the AFI are deduced by applying a factor of 0.8 m^3 u.b./m^3 o.b., according to Jonas (1997). Sources: FMAF (1991), Bittermann and Gerhold (1995), Schieler *et al*. (1996).

One additional source for the differing numbers of wood harvest is the area of exploitable forests, which was 3.331 mio. ha or 86% of the total forest area in 1990 (3.878 mio. ha) (Schieler *et al*., 1996). The HEN and forest inventory refer to this area, whereas the wood balance also considers non-forest areas.

5.1.2.5 A possible way towards consistency of the three reporting systems

The previous section emphasized the possible range of wood harvest, while this section discusses one of probably several ways to achieve consistency for the three reporting systems. As the HEN is part of the wood balance, consistency is sought for forest inventory and wood balance in particular.

The total harvested wood in the Austrian wood balance (18.635 mio. m^3 u.b. for the period 1989–1991)[16] is substantially higher than that of the AFI (15.877 mio. m^3 u.b. for the period 1986–1990),[17] when we assume the conversion factor is 0.8 according to Jonas (1997). In order to link the two reporting systems together, it should be discussed how these inconsistencies can be overcome.

First, wood harvest (894 * 10^3 m^3 u.b. for the period 1989–1991) from non-forest areas must be subtracted from the total wood harvest of the wood balance because it is not included in the forest inventory. This leaves 17.741 mio. m^3 u.b. with which to compare. The Austrian wood balance does not report uncertainties, whereas the forest inventory specifies an uncertainty interval (±3.56%). If we take the conversion factor of 0.8, we end up with an uncertainty band of the forest inventory that ranges from 15.312–16.442 mio. m^3 u.b. It is clear, however, that this interval cannot explain the difference up to 17.741 mio. m^3 u.b. of the wood balance.

Another possible source of inconsistency emerges from the unusually high storm damages in 1990, which seems to increase the mean value for 1989 to 1991. However, this effect is, on the one hand, lowered by a decrease of harvest in 1991 and is, on the other, also too small to serve as an explanation. We also do not know to which extent the figures for 1990 influence the two statistical sources differently. This effect is therefore not considered any further.

Yet another source for inconsistency are conversion factors. The numbers reported by the HEN, which represents the major part of wood harvest of the wood balance, are obtained by factors that are either officially recommended (see, e.g., the following section and *Tables A7* and *A8* in the Appendix), or are individually deduced from experience by each of the forest enterprises and farmers. Therefore, uncertainties underlying the conversion factors can hardly be quantified and thus have to be addressed by so-called tacit knowledge.

Therefore, we focused our interest on the conversion of wood inventory data to the basic unit of the wood balance, which is m^3 u.b. As previously mentioned, the conversion factor used so far to convert m^3 o.b. into m^3 u.b. is 0.8, meaning that 20% of the wood harvest is dedicated to bark, harvest losses, and *Schwund* (that is the decrease of volume as a result of decreasing moisture content). According to Böswald (1996), Lohmann *et al*. (1986) Schwaiger (1999), Jonas (2001) and Weiss *et al*. (2000), this factor must be even lower (0.7–0.75). Although the application of this more realistic

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[16] As Bittermann and Gerhold (1995) include bark in the item “other domestic supply”, bark has to be subtracted from the total domestic supply.

[17] Values of the AFI have been converted to m^3 u.b., aiming at providing a common basis for comparison. Applying a smaller conversion factor than 0.8, for example, 0.7 as recommended by some forestry experts (e.g., Hannes Schwaiger of JRG) would even lead to a larger discrepancy.

conversion factor may be right from the view of a practitioner, it poses additional problems since the gap between the forest inventory and the wood balance is in consequence even larger. In addition, the application of this lower factor in calculation leads to a large amount of bark, for which the destination has to be explained, as Bittermann and Gerhold (1995) come up with a consistent supply and demand of domestic wood, including bark. If the amount of bark is therefore substantially larger, a complete revision of the wood balance must be postulated.

Given the two reporting systems and trying to link them consistently without changing their inner structure, led us to favor two alternatives:

1. To calculate the conversion factor, which transforms the m^3 u.b. value of the total harvest of the Austrian wood balance into the m^3 o.b. value of the AFI, and then to check if this conversion factor is plausible from an expert's view.
2. To determine the hypothetical uncertainty band of the Austrian wood balance that is necessary to at least border the uncertainty of the forest inventory, thereby accounting for the uncertainty of the conversion factor "m^3 o.b. to m^3 u.b.".

First alternative: Calculation of a virtual conversion factor

Bittermann and Gerhold (1995) illustrate that bark is not considered in the former versions of the wood balance. This was because the felled wood had been barked in the wood and the bark had also been left there. Today, in contrast, decortication is not undertaken until the processing in industry and bark is then utilized to a major degree. To account for the share of bark from the timber used in production processes, Bittermann and Gerhold (1995) assume 10% bark to accrue for 95% of the total timber production, and 11% bark for 100% of wood demand in the board industry (*Plattenindustrie)*. This leads to a fraction of bark that is approximately 11% of the total roundwood harvest.[18] By applying these factors, Bittermann and Gerhold (1995) come up with an average domestic production of 1.453 mio. m³ of bark for 1989–1991. If we, for example, apply a factor of 0.75 for converting the m³ o.b. values of the forest inventory into m³ u.b. values of the wood balance, as is being done by Jonas (2001), we would come up with a calculatory (theoretical) maximum production of 4.961 mio. m³ of bark: 19.845 mio m^3 o.b. * 0.75 = 14.883 mio m^3 u.b. (see also, *Table 4* for applying the conversion factor 0.894, which results in a hypothetical production of 2.104 mio m^3 of bark). This is by far too much (>3 times) to be explained by the demand side of the Austrian wood balance. Our first-order solution is thus to apply a factor of 0.894, which is used by Bittermann and Gerhold (1995) to get a consistent, but still tentative, link between forest inventory and the wood balance.

In a study recently published by the Austrian Federal Environment Agency, Weiss *et al*. (2000) also address this resulting virtual conversion factor, which represents quite a large underestimation of the real world. Weiss *et al*. (2000) come up with additional assumptions for this obvious discrepancy.

[18] This value is gained by dividing bark harvest with the harvest of roundwood. According to the Austrian Timber Trade Usance (Wiener Börsenkammer, 1985) the amount of bark resulting from spruce and fir is 12% of the volume, and for pine and larch wood 13% of the volume.

Taking all the various factors for inconsistencies into account, the chosen procedure seems to be one of many plausible ways of bringing the two statistics together. Nevertheless, it is important to emphasize that our conversion factor is a "virtual" one to adjust different statistics and does not reflect a real physical relationship.

Table 4 illustrates this conversion. However, the factor for calculating the fraction of bark requires further proof in the future. Moreover, because the supply side of the Austrian wood balance is mainly derived from the demand side (Bittermann and Gerhold, 1995),[19] meaning that all items except the HEN are based on assumptions, further deliberations will have to focus on that issue in particular, and will also have to include imports and exports of wood to reduce uncertainties. In the final version of the Austrian carbon consistent database a different approach is applied to make the two reporting systems consistent (Jonas, 2001). The main focus there, is pointed at the uncertainty issue and a factor of 0.75 is applied to convert m^3 u.b. from m^3 o.b.

Second alternative: Assessing the uncertainty band of the wood balance

Taking into account the extreme values of the uncertainty band of the forest inventory and the uncertainty band of the conversion factor "m^3 o.b. to m^3 u.b.", we do not get up far enough with the resulting m^3 u.b. values to overlap with the wood balance which, according to section 4.5, is our minimum consistency requirement.

Since no uncertainty band is reported for the wood balance, we thus ask how big the uncertainty band of the m^3 u.b. values of the wood balance must at least be to border the uncertainty of the forest inventory, thereby accounting for the uncertainty of the conversion factor m^3 o.b. to m^3 u.b and whether this uncertainty band is plausible from an expert's view.

Our procedure can be best explained by first having a look at *Figure 5*. There, the left side of the figure can be visualized to represent the uncertainty of the AFI, thereby accounting for the uncertainty of the m^3 o.b/m^3 u.b. conversion factor. This uncertainty band is quantified in *Table 5*. Thus, the lower uncertainty limit of the forest inventory, which is 19.138 mio. m^3 o.b., times the lower limit of the m^3 o.b/m^3 u.b. conversion factor, which is 0.7, results in 13.397 mio. m^3 u.b. Applying the same procedure for the upper limits of the forest inventory and the m^3 o.b/m^3 u.b. conversion factor leads to an upper uncertainty limit of 16.442 mio. m^3 u.b. From *Table 5* it is now evident, that the gap between the mean value of the wood balance for the years 1989–1991 and the upper limit of the forest inventory times, the upper limit of the m^3 o.b/m^3 u.b. conversion factor is 1.299 mio. m^3 u.b. We therefore take this value as the theoretical necessary uncertainty band of the wood balance, which is at least required to fulfill our minimum consistency requirement. In *Figure 5*, this would mean that the lower limit of this newly calculated uncertainty band of the wood balance just equals the upper limit of the forest inventory, considering the uncertainty of the m^3 o.b/m^3 u.b. conversion factor. As we do not know of any symmetrical or asymmetrical distribution of the wood balance, we assume a symmetrical uncertainty band that therefore equals 17.741 mio. m^3 u.b. ±7.3%

[19] The starting point of the methodological approach of Bittermann and Gerhold (1995) for building the Austrian wood balance is the demand side of wood as it is statistically better reported. Therefore, the underestimation of the supply side is assessed based on this data but as far as possible, bearing plausibility in mind (Bittermann and Gerhold, 1995).

(*Table 5*). Building upon our knowledge, we are of the opinion that this uncertainty band is plausible.

Therefore, to calculate carbon flows on the basis of the m^3 u.b. values of the wood balance, which is described in detail in section 5, we start by taking the extreme values of each of its items, which result from the reported values of the wood balance ±7.3% (*Table 5*).

Table 4: Consistency of wood harvest (annual fellings) of the AFI and the domestic wood production according to the Austrian wood balance by applying the conversion factor 0.894 m^3 u.b./m^3 o.b. Sources: Bittermann and Gerhold (1995); Schieler *et al*. (1996); IIASA; cf., also FMAF (1990; 1991; 1992).

Schieler *et al.* (1996)	Austrian Wood Inventory – Conversion to m^3 u.b.				Austrian Wood Inventory – Original data			
	Uncertainty interval (±10^3 m^3 u.b.)	Upper value (10^3 m^3 u.b.)	Lower value (10^3 m^3 u.b.)	Mean value 1986–1990 (10^3 m^3 u.b.)	Uncertainty interval (±10^3 m^3 o.b.)	Upper value (10^3 m^3 o.b.)	Lower value (10^3 m^3 o.b.)	Mean value 1986–1990 (10^3 m^3 o.b.)
Annual increment (hypothetical in the case of m^3 u.b. values)								
Coniferous wood	458	23412	22497	22954	512	26188	25164	25676
Deciduous wood	168	5300	4963	5132	188	5928	5552	5740
Total	493	28579	27592	**28086**	552	31968	30864	**31416**
Annual fellings (hypothetical in the case of m^3 u.b. values)								
Coniferous wood	575	14936	13786	14361	643	16707	15421	16064
Deciduous wood	217	3597	3163	3380	243	4024	3538	3781
Total	632	18373	17109	**17741**	707	20552	19138	**19845**
Resulting amount of bark (hypothetical)								2104

Bittermann and Gerhold (1995)	Austrian Wood Balance – Original data			
	1989 (10^3 m^3 u.b.)	1990 (10^3 m^3 u.b.)	1991 (10^3 m^3 u.b.)	Mean value 1989–1991 (10^3 m^3 u.b.)
Domestic wood production				
Fellings (HEN)	**13822**	**15711**	**11492**	**13675**
Deciduous wood	***2381***	***2265***	***2023***	***2223***
Coniferous wood	***11441***	***13446***	***9469***	***11452***
Roundwood	**11146**	**12939**	**9055**	**11047**
Deciduous wood	1019	1012	835	955
Coniferous wood	10127	11927	8220	10091
Ratio deciduous wood/coniferous wood (%)	9.1	7.8	9.2	8.6
Fuelwood	**2676**	**2772**	**2437**	**2628**
Deciduous wood	1362	1253	1188	1268
Coniferous wood	1314	1519	1249	1361
Ratio deciduous/coniferous wood (%)	51	45	49	48
Other wood from forest soils	**3809**	**3735**	**3479**	**3674**
Roundwood	2259	2046	1868	2058
Fuelwood	1550	1689	1611	1617
Total wood from forest soils	**17631**	**19446**	**14971**	**17349**
Other domestic wood supply (without recycled re-used wood)	**1225**	**1275**	**1358**	**1286**
Wood from non-forest areas	875	875	933	894
Chips from forest residues (*Waldhackgut*)	350	400	425	392
Total Harvest (without recycled re-used wood)	**18856**	**20721**	**16329**	**18635**
Harvest without bark and wood from non-forest areas	**17981**	**19846**	**15396**	**17741**

Table 5: Calculating the hypothetical minimum uncertainty band of the Austrian wood balance. Sources: Bittermann and Gerhold (1995), Schieler *et al*. (1996), IIASA.

Measured and/or calculated m^3 o.b. values	Upper and lower limit of conversion factor m^3 o.b. to m^3 u.b. and vice versa	Reported and/or calculated m^3 u.b. values
(mio. m^3 o.b.)		(mio. m^3 u.b.)
Forest inventory		
19845	0.7	13892
19138	0.7	13397
20552	0.7	14386
19845	0.8	15876
19138	0.8	15310
20552	**0.8**	**16442**
		Wood balance
25344	1.43	17741
22176	1.25	17741
27199	1.43	19040
23489	1.43	16442
23800	1.25	19040
20552	**1.25**	**16442**
Resulting theoretical uncertainty band of the wood balance	(± mio. m^3 u.b.)	**1299**
	(± %)	**7.32**

5.1.2.6 From wood harvest to energy balances

Further important data sources for obtaining consistency with wood harvest are the energy balances of AIER (1996) for 1986–1994[20] and ACSO (1992a; 1993a; 1994) for 1989, 1990 and 1991, because fuelwood balances are included.

AIER compiled national energy balances from 1955 to 1994, whereas ACSO publishes national energy balances since 1969. The initially reported differences were almost completely removed (AIER, 1996). One main difference still remaining is the composition of consumption domains. The procedure of compiling the energy balances was adjusted as follows: AIER established a preliminary energy balance six months after the year under review and replaced it by the final energy balance after the ACSO final balance became available.

[20] AIER no longer publishes the energy balance (Bittermann, 1999).

It is important to emphasize that from 1989 onwards the ACSO energy balance has been changed twice compared to previous ones. Firstly, the classification of energy sources (renewables, in particular) has been readjusted to new requirements. Secondly, the results of the wood balance analysis carried out at the Department of Environment at ACSO showed that fuelwood data, as well as sawn wood residues, products and others, had to be reviewed. As a consequence, a compilation of a detailed fuelwood balance under close cooperation with the Austrian Federal Forest Agency[21] was developed for the years since 1988, which afterwards became part of the previously discussed Austrian wood balance. Finally, the updated calculation of fuelwood and biogenic fuels resulted in a significant increase of renewable shares from 1987 to 1988 (ACSO, 1992a).

5.1.2.7 Consistency of fuelwood flows

Fuelwood flows represent the major share of wood harvest for energetic use (approximately 60% according to the Austrian wood balance). Therefore, the next step in our study was to look for consistency of fuelwood flows with total wood harvest. As mentioned earlier, we were aware of the so far unresolved discrepancy between the fuelwood production reported by the Austrian wood balance (Bittermann and Gerhold, 1995) and the fuelwood demand, reported by AIER (1996).

In this respect, Jonas (1997) states that inconsistencies concerning fuelwood supply in the energy statistical data of AIER and the wood balance statistical data of ACSO are considerable and require a compensatory correction of the carbon flow balance in the wood industry. For example, AIER (1996) statistics give a mean value of 88,090 TJ for 1989–1991, which equals 2.634 mio. t C, after multiplication with the IPCC recommended carbon conversion factor for wood (29.9 t C/TJ). ACSO, on the other hand, give a mean value of fuelwood use of 5.354 mio. m^3 u.b. for 1989–1991, which converts to 6.693 mio. m^3 o.b. (applying a factor of 0.8^{-1} for converting m^3 u.b. into m^3 o.b.) and finally to 1.378 mio. t C (following the conversion instructions of Jonas, 1997). Hence, fuelwood related carbon values of the two statistical sources differ by a factor of about 1.9.

The procedure of Jonas (1997) pursues to link different statistical data on the carbon level. However, in this study we are initially attempting to check consistency on the level of material flows, that is wood flows in particular, according to the procedure outlined in section 4.

Therefore, in the following paragraphs, the aim is to achieve consistency for the energetic use of fuelwood of the Austrian wood balance (Bittermann and Gerhold, 1995), the Austrian Final Energy Balance (ACSO, 1992a; 1993a; 1994), and the Austrian fuelwood balance (AIER, 1996).

Bittermann and Gerhold (1995) split the energetic use of wood into fuelwood, sawn wood residues/chips from forest residues, as well as recycled re-used wood, using the common unit of m^3 u.b. and also considering imports and exports of fuelwood. By contrast, AIER (1996) produced its own fuelwood balance, leaving other biogenic

[21] In particular, Mrs. Wakolbinger's expertise.

energy sources combined to the total energy balance (*Table 6*). Besides domestic fuelwood production, fuelwood imports and exports are also included. In contrast to the wood balance, the reporting unit here is metric tons. It is important to mention, that there is no further specification on this unit (e.g., fresh weight, air dry weight, dry matter). ACSO (1992a, 1993a, 1994) reports energetic end use of fuelwood and biogenic fuels in metric tons as well as their share of domestic production. Additionally, ACSO (1992a; 1993a; 1994) further divides domestic fuelwood and other biogenic fuel production into supply domains of agriculture, forestry and civil engineering. The latter should therefore coincide with the share of recycled re-used wood of the wood balance (*Table 7*).

Table 6: Classification of *Other energy carriers* in the AIER energy balance.
Source: AIER (1996).

Raw energy carriers

- **Fuelwood**
- Biogenic fuels
  - **Chips, bark, saw residuals, chips from forest residues**, straw, biogas, sewer gas, landfill gas, RME (rape methyl ester)
- Environmental heat, sun energy, wind energy:
  - Energy from heat pumps, geothermal energy, solar current, solar heat
- Combustible wastes
  - Waste, other wastes, spent liquor, sludge of the paper industry

Starting with the Austrian wood balance, the total energetic use of fuelwood in the broader sense, that is fuelwood, sawn wood residues, chips from forest residues and recycled re-used wood, is 8.471 mio. m³ u.b. in 1989, 8.556 mio. m³ u.b. in 1990, and 8.690 mio. m³ u.b. in 1991. Of that, the largest fraction is fuelwood in the narrower sense (5.313 mio. m³ u.b. in 1989, 5.469 mio. m³ u.b. in 1990, and 5.280 mio. m³ u.b. in 1991) followed by sawn wood residues/chips from forest residues and recycled re-used wood (*Table 7*). The energetic use equals domestic production plus imports minus exports plus/minus changes of stocks, whereas imports, exports, and changes of stocks are very small compared to the domestic production of fuelwood. Concentrating on the domestic production of fuelwood in the narrower sense results in 5.101 mio. m³ u.b. in 1989, 5.336 mio. m³ u.b. in 1990, and 4.981 mio. m³ u.b. in 1991 (*Table 7*).

Including the share of recycled re-used wood into the domestic production of fuelwood results in 6.284 mio. m³ u.b. in 1989, 6.447 mio. m³ u.b. in 1990, and 6.311 mio. m³ u.b. in 1991 (*Table 7*).

Table 7: Fuelwood flows in the Austrian wood balance.
Sources: Bittermann and Gerhold (1995), IIASA.

	Austrian Wood Balance			
	Original data			Mean value
	1989	1990	1991	1989–1991
	[10^3 m^3 u.b.]	[10^3 m^3 u.b.]	[10^3 m^3 u.b.]	[10^3 m^3 u.b.]
Energetic use	8471	8556	8690	8572
Fuelwood	5313	5469	5280	5354
Saw residual wood/Chips from forest residues	1975	1976	2080	2010
Recycled re-used wood	1183	1111	1330	1208
Energetic use of fuelwood	6496	6580	6610	6562
Change of stocks				
Fuelwood	-1	42	-61	-7
Import				
Fuelwood	212	177	245	211
Export				
Fuelwood	1	2	7	3
Production				
Fuelwood	2676	2772	2437	2628
Deciduous wood	1362	1253	1188	1268
Coniferous wood	1314	1519	1249	1361
Other wood from forest soils				
Fuelwood	1550	1689	1611	1617
Other domestic wood supply (without recycled re-used wood)	**2662**	**2766**	**2789**	**2739**
Wood from non-forest soils	875	875	933	894
Bark	1437	1491	1431	1453
Chips from forest residues	350	400	425	392
Recycled re-used wood	1183	1111	1330	1208
Fuelwood supply	5313	5513	5226	5351
Domestic production of fuelwood (including wood from non-forest soils)	**5101**	**5336**	**4981**	**5139**
Total domestic production of fuelwood (including recycled re-used wood)	6284	6447	6311	6347

On the other hand, if we consider the figures given by the Austrian fuelwood balance (AIER, 1996), we are confronted with the mass unit (t freshweight). Thus, production of fuelwood equals 5.631 mio. t fw in 1989, 5.774 mio. t fw in 1990, and 5.093 mio. t fw in 1991 (*Table 8*). In order to bridge the gap between the two reporting systems, we convert the figures by multiplying them with the conversion factor (0.807 t fw/m³ u.b.)$^{-1}$, which has been used until recently by AIER and ACSO. The conversion results in the domestic production of 6.312 mio. m³ u.b. in 1991, which equals (though there is some rounding error) the domestic production of fuelwood ***including the share of recycled re-used wood,*** according to the Austrian wood balance (Bittermann and Gerhold, 1995). It is therefore crucial to emphasize the different definitions of fuelwood production underlying the two reporting systems.

Table 8: Fuelwood flows in the AIER fuelwood balance.
Sources: AIER (1996), IIASA.

	Austrian Fuelwood Balance AIER (1996)			
	Conversion factor **0.896**	Conversion factor **0.896**	Conversion factor **0.807**	
	1989 [1000 t]	1990 [1000 t]	1991 [1000 t]	Mean value 1989–1991 [1000 t]
Production of fuelwood	5631	5774	5093	**5499**
Import of fuelwood	191	159	197	**183**
Change of stocks (- = increase)	1	-38	49	**4**
Export of fuelwood	1	2	6	**3**
Consumption of fuelwood	**5822**	**5894**	**5334**	**5683**
Conversion to m^3 u.b. using ACSO old conversion factors, and including the correction for the years 1989 and 1990 (which were 0.896)	[10^3 m^3 u.b.]	[10^3 m^3 u.b.]	[10^3 m^3 u.b.]	[10^3 m^3 u.b.]
Production of fuelwood	**6285**	**6444**	**6312**	**6347**
Import of fuelwood	**213**	**178**	**245**	**212**
Change of stocks (- = increase)	**1**	**-42**	**61**	**7**
Export of fuelwood	**1**	**2**	**7**	**3**
Consumption of fuelwood	**6497**	**6578**	**6610**	**6562**

However, the 1989 and 1990 figures did not fit together, for which the reason was not clear in the first run. Further investigations revealed that before 1991 a different conversion factor of 0.896 t fw/m³ u.b. had been applied by AIER (1996). Taking all these differences into account results in coincident statistics (*Tables 7* and *8*). Some small differences are due to rounding errors.

A listing of the energetic end use and domestic production of the Austrian Final Energy Balance (ACSO, 1992a; 1993a; 1994) completes the picture of consistent fuelwood statistics (*Table 9*). The same conversion factors as previously described have also been applied here. Besides some rounding errors, an explanation for the difference in domestic fuelwood production in 1989 (and possibly in 1990) between the Austrian Final Energy Balance and the Austrian wood balance remains open.

In conclusion, the putative carbon inconsistency raised by Jonas (1997) is due to inexplicitly defined items and conversion factors by the AIER (1996) study. Furthermore, this illustrates how important a consistent material flow framework is for FCA.

Table 9: Fuelwood flows in the Austrian final energy balance.
Sources: ACSO (1992a; 1993a; 1994), IIASA.

		Austrian Final Energy Balance (ACSO, 1992a, 1993a, 1994)			
		1989 [1000 t]	1990 [1000 t]	1991 [1000 t]	**Mean value 1989–1991** [1000 t]
Energetic end use					
	Fuelwood	5822	5894	5335	5683
	Biogenic fuels	1690	1847	1962	1833
Domestic production					
Agriculture and Forestry					
	Fuelwood	4951	4803	4020	4591
	Biogenic fuels	567	1123	1145	945
Civil engineering					
	Fuelwood	1040	971	1073	1028
Others					
	Biogenic fuels	1550	963	1180	1231
Conversion to m^3 u.b.					
Applying 0.896 factor for 1989 and 1990		1989 [1000 m^3 u.b.]	1990 [1000 m^3 u.b.]	1991 [1000 m^3 u.b.]	**Mean value 1989–1991** [1000 m^3 u.b.]
Energetic end use					
	Fuelwood	**6497**	**6578**	**6610**	**6562**
	Biogenic fuels	1886	2061	2431	2126
Domestic production					
Agriculture and Forestry					
	Fuelwood	**5526**	**5360**	**4982**	**5289**
	Biogenic fuels	633	1253	1419	1102
Civil engineering					
	Fuelwood	**1161**	**1084**	**1330**	**1191**
Others					
	Biogenic fuels	1730	1075	1462	1422

5.1.3 Austrian wood flows reported by other studies

The comprehensive approach of the Austrian wood balance covers most of the Austrian domestic wood flows by balancing the supply and demand sides. In addition, imports and exports of roundwood and fuelwood are also considered. However, the large share of imports and exports of refined wood products like, for example, furniture, are not taken into account. To ensure consistent carbon flows according to our general approach described in section 4, additional studies have to be considered besides Jonas (1997) and Orthofer (1997).

Some of these studies are either conducted once like, for example, those of the *Center for Environmental Protection and Nature Conservation at the University of Soil Sciences in Vienna* (Wimmer and Halbwachs, 1992), or more or less periodically updated like those of the *Institute for Interdisciplinary Studies of Austrian Universities* (Steurer, 1992; 1994; Hüttler *et al.*, 1996), or are annually published like the annual report of the association *Forum for Forest, Board and Paper* (e.g., Herzog, 1998).

For example, Wimmer and Halbwachs (1992), who mainly concentrate on statistical data from the period 1980–1990, also consider the total amount of imported and exported wood products. The difficulty in explaining the differences to our study is that

Wimmer and Halbwachs (1992) do not report in detail on underlying data or about conversion factors.

The 1990 material flow analysis of Austria (Hüttler *et al.*, 1996) is built upon the Austrian wood balance and therefore can, in principle, be linked consistently. Nevertheless, due to its rather rough approach, conversion factors must be reviewed critically. For example, since the common unit of material flows in the material flow analysis (MFA) is (t fw), the authors use a common conversion factor of 0.86 (t/m^3 u.b.) for calculating aggregated wood mass flows. It is not clear, however, if the authors refer to freshweight, air dry weight, or dry matter. As we point out in the next section, this conversion factor is somewhat too high to be taken as an aggregated conversion factor for all wood flows. In general, the material flow analysis is strongly recommended to serve as the basis for calculating future full carbon budgets of Austria, provided that it is periodically updated.

The association Forum for Forest, Board and Paper (e.g., Herzog, 1998) creates annually updated sector statistics of wood imports and exports for Austria, based on data from ACSO. Therefore, consistently linked, we consider this data as generously suited to serving as an extension to the Austrian wood balance.

The 1990 data of wood flows are also reported by international organizations, in particular the United Nations Economic Commission for Europe (UNECE). The UNECE/FAO report “The Forest Resources of the Temperate Zones” is based on the AFI 1986/90 (UNECE/FAO, 1992), thereby using preliminary results and is thus rather pointless to be further considered for the database.

The *Forest Product Statistics*, also assembled by the UNECE (UNECE/FAO, 1994) serves as another important data source, particularly for imports and exports of wood flows. The figures appearing in the statistical tables of the report are obtained from the statistical returns supplied by the governments to the secretariat and sometimes supplemented by data from semi-official or non-governmental sources (UNECE/FAO, 1994). The main differences to the Austrian wood balance are, on the one hand, differences in reported removals of wood, which are significantly higher than the HEN and do not show the 1990 peak due to storm damage. On the other hand, the Forest Product Statistics include the total import and export of refined wood products. Due to their comprehensive approach, the Forest Products Statistics may serve as an additional data source for the carbon consistent database.

5.1.4 Concluding remarks to the consistency of wood related carbon flows

According to our general approach in building a carbon consistent database (section 4) we are now in the position to speak of consistently adjusted wood related carbon flows on the basis of the AFI, the Austrian wood balance, the HEN of the Federal Ministry of Agriculture and Forestry, and of the energy and fuelwood balances of AIER and ACSO. Due to time constraints of the IIASA stay, it was not possible to go beyond these wood flows. Thus, the imports and exports of wood and wood products, which are reported by the foreign trade statistics in general, and for example, the association Forum for Forest, Board and Paper in particular, are not considered any further. Instead, we further proceed with an exemplary discussion on the impact of conversion factors on carbon flows.

These additional wood flows are illustrated in a consistent fashion in the final version of the Austrian carbon consistent database (Jonas, 2001).

As Orthofer *et al*. (2001) also built a consistent framework of wood flows to set up a basis to feed their Austrian Carbon Balance Model, they show another alternative of balancing the wood flows.

5.1.5 Carbon flows: The role of conversion factors

The previous secions mainly implicitly indicated the importance of conversion factors, whereas this section explicitly focuses on the role of conversion factors. Aspiring consistency of wood flows must bridge the gap between different measurement units of wood flows. For example, as already intensively discussed, forest inventory accounts for m^3 o.b., whereas all other surveys account for m^3 u.b. Hence, a set of conversion factors is needed, allowing the conversion of the forest inventory data to that of the HEN, the wood balance, and to all of the other surveys on wood flows. These conversion factors are crucial and must therefore be chosen very carefully.

In reviewing studies on Austrian wood flows, it became evident that there is not only a lack of using common conversion factors for the conversion of m^3 o.b. into m^3 u.b., but there is also a lack of commonly applied conversion factors to converting volume, weight, energy, and carbon contents into each other. In order to bridge this gap in the Austrian carbon balance framework, it was decided to undertake a short telephone survey[22] with experts to identify the officially and scientifically used conversion factors in Austria. The following institutions were contacted upon the recommendation of Dr. Knieling from the Federal Ministry of Agriculture and Forestry:

- Austrian Standards Institute *(Österreichisches Normungsinstitut)*;
- Forum for Forest, Board and Paper;
- Institute of Wood Science and Technology (University of Soil Sciences);
- Wood Science Austria/Arsenal;
- Federal Testing Institute for the Timber Industry, Higher Technical College, Mödling; and
- Proholz Austria.

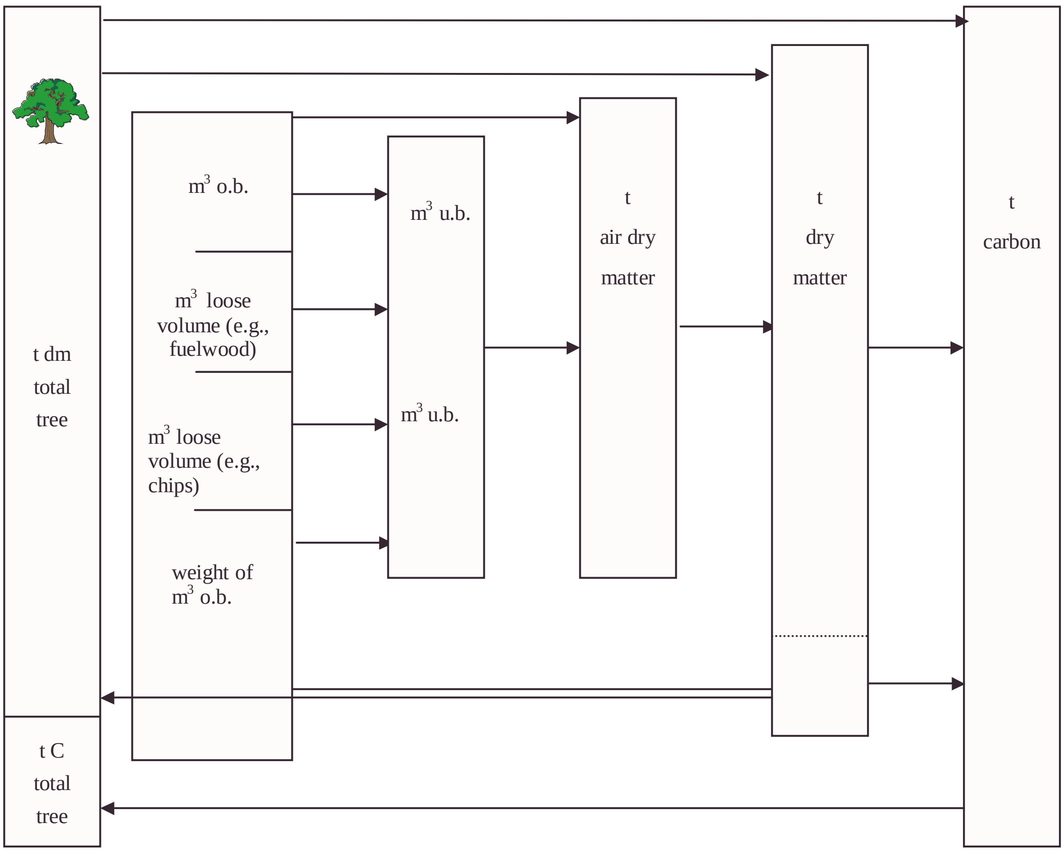
The survey revealed that:

- none of the institutions are actually dealing with the quantification of carbon flows;
- the most usable data sources for conversion factors in the wood industry are the Austrian Timber Trade Usance (Wiener Börsenkammer, 1985) and the ÖNORM[23] 7132 (Österreichisches Normungsinstitut, 1998), supplemented by specific data sets on wood physics (cf., e.g., Sell, 1997); and

[22] The survey was restricted by the time available.
[23] ÖNORM is Austrian Standard.

- the Forum for Forest, Board and Paper association had recently changed the conversion factors that they applied for calculating their annual wood balance of the wood industry sector (Anonymous, 1998).

A summary of commonly applied conversion factors is given in *Tables A5* to *A16* in the Appendix, based on the results of this survey and supplemented by conversion factors already used in (the aforementioned) carbon studies. These tables serve more to show the large number of different conversion factors used by the wood industry than to give a complete picture on existing conversion factors. Therefore, the tables are incomplete and built upon marginal utility. *Figure 8* illustrates the kind of conversion steps towards carbon content are reported in the literature.



Note:
m^3 o.b. *(Vorratsfestmeter)*: 1 m^3 o.b. equals 1 m^3 of standing wood including bark, measured and calculated by the AFI.
m^3 u.b. *(Erntefestmeter)*: 1 m^3 u.b. equals 1 m^3 o.b. less harvest losses and bark volume (tradable mass).
m^3 loose volume (e.g., fuelwood) *(Raummeter)*: 1 m^3 loose volume equals 1 m^3 of piled wood including air spacing.
m^3 loose volume (e.g., chips) *(Schüttraummeter)*: 1 m^3 loose volume (e.g., chips) equals 1 m^3 loose volume (e.g., fuelwood) of poured wood fragments.
Weight of m3 o.b.*(Vorratsfestmeter, Gewichtsmaß)*: weight of 1 m^3 o.b. in tons.
Source: Schwaiger (1999).

Figure 8: Conversion steps in use for wood and carbon flows in Austria.
Source: IIASA.

5.1.6 Uncertainty of conversion factors

As already discussed in section 4.5, uncertainty of conversion factors can only be calculated if there are at least two different reported values for each conversion factor. But this is not even the case for all of the conversion factors used in this study.

To assess the uncertainty of conversion factors in a simplified fashion, we decided to take the maximum and minimum reported values, then calculate the medium value and determine the uncertainty band by subtracting the average from the upper value and transform it into percentage values. We are certainly aware of other approaches, but do not consider them here. A more complex approach, applying probability function, standard deviation, and error propagation is being elaborated by Jonas (2001).

5.1.6.1 Conversion factors for aggregated wood flows

A basic challenge in assessing the uncertainty of wood related carbon flows is the handling of aggregated wood flows. We usually find these when balancing wood flows on our so-called Level 1 or national level. For instance, the position for timber (*Nutzholz*) of the Austrian wood balance consists of coniferous and deciduous wood. These two items are again aggregated levels of different coniferous and deciduous tree species like spruce, fir and pine, and beech, oak and maple, respectively. Moreover, all kinds of wood are characterized by different values of density and moisture (cf. *Table A11* in the Appendix). Thus, for taking different shares of wood into account for aggregated conversion factors, limits are set by available data and the manageable level of complexity.

The problem of aggregated conversion factors may be illustrated by the example of the Austrian material flow accounting. Hüttler *et al*. (1996) use a general conversion factor of 0.86 to transform 1 m^3 u.b. of wood into tons of mass weight for the aggregated wood harvest. The authors do not make clear, which degree of moisture underlies this conversion factor. This is a very common problem in wood flow accounting, and is not trivial by any means. Moreover, *Table A11* in the Appendix makes clear, that this conversion factor may be valid for beech, but is too high to be used as a mean value for all aggregated wood flows: beech wood accounts for only 8.1% of total fellings in Austria (Schieler *et al*., 1996, *Table A17* in the Appendix).

Also other reporting systems appear to use aggregated conversion factors that are too high, for example, the UNECE/FAO (1994) factors for saw logs. Otherwise, conversion factors for fuelwood are more significantly in the range being reported by official Austrian institutions and comparative data sets (e.g., Sell, 1997).

In the case of the Austrian wood balance, Bittermann and Gerhold (1995) do not separate the supply and demand of wood into shares of coniferous and deciduous wood. Since the share of the tree species is only reported for the annual increment and annual fellings of the AFI in detail (*Table A17* in the Appendix), we take these numbers to deduce an aggregated conversion factor, which we then also apply to the Austrian wood balance. The calculation of a weighted average of fuelwood and roundwood fellings of the forest inventory is done by summation of the products of the share of a particular tree species and the mean density value reported for this particular tree species by Sell

(1997). We take Sell's numbers since they are built on a large sample. It is obvious, however, that they are not based on Austrian measurements.

Thus, the calculated aggregated conversion factor for coniferous wood fellings is 0.47 t air dry matter/m^3 u.b., whereas the calculated conversion factor for deciduous wood fellings is 0.7 t air dry matter/m^3 u.b. Aggregating conversion factors of coniferous and deciduous wood fellings results in an average density conversion factor for the total fellings of 0.51 t air dry matter/m^3 u.b. This is, for example, only 59% of the conversion factor used by Hüttler *et al*. (1996) or even only 59% used by Steurer (1994) and also significantly below UNECE/FAO (1994).

The only differentiation of survey categories in the HEN below the level of coniferous and deciduous wood is the separation of spruce/fir and beech shares.[24] Hence, the calculation of an aggregated conversion factor is not appropriate. The Austrian wood balance itself, which is built upon the HEN, only differentiates between coniferous and deciduous wood, which also makes it impossible to calculate an aggregated conversion factor.

In conclusion, conversion factors derived from species shares of the AFI are also used for calculating the density of coniferous and deciduous wood supply in the wood balance. Building upon that, conversion factors are derived for roundwood (timber), fuelwood, and saw residuals.

Moisture contents of wood

The next step is the conversion of moist wood into dry wood (*darrtrockenes Holz*). According to *Table A11* in the Appendix, the average moisture content of air dry wood is 13.5%, the bandwidth ranging from 12–15% (Sell, 1997). However, ACSO (1998; 1999) recently adapted the moisture content of air dry fuelwood to account for 20% (formerly 15%), a value also used by the IPCC (1995; 1996a,b). Also, the newly applied factors for the moisture contents of chips from forest residues (25%), sawn wood residues and chips (10–45%) are substantially higher than the old ones (15%). As Sell (1997) offers a consistent and comparable data basis for all wood species reported by the AFI, we apply the referring values for the moisture contents of roundwood and fuelwood.

As mentioned above, we are aware of the general uncertainty of the moisture contents of wood. Whereas standing or recently cut wood is considered to contain up to 30% of water, and felled wood is even able to store up to 50% of water when stored in nature, "air dry wood" is given by the time the water content is below 20% of the total mass. To reach air dryness, at least one year of storage is required; in the case of beech and oak

[24] The share of spruce/fir and beech fellings reported by the HEN amount to 87% of coniferous timber and 67% of deciduous timber in 1990. For 1991, the share of spruce/fir is also 87%, whereas the share of beech is 66%. In contrast, the figures of the Austrian wood inventory are 82% spruce/fir and 42% beech for the *total* amount of the coniferous and deciduous fellings. Hence, further proof of consistency does not seem possible.

this period is at least two years.[25] In addition, because the moisture content of wood is roughly in balance with humidity the water content is constantly changing.

The Austrian wood balance, for example, covers all types of wood, from freshly cut wood to wood processed in industry, and so forth. It is therefore not possible to handle this issue in more detail.

Carbon contents of dry wood

Carbon contents of wood ranges from 0.45 t C/t dm to 0.508 t C/t dm, resulting in an average factor of 0.479 t C/t dm. However, the sample is very small and mainly consists of already aggregated values (*Table A14* in the Appendix).

5.2 Size and Uncertainty of Some Wood Related Carbon Flows

5.2.1 Carbon flows of the forest inventory fellings

Tables 10 and *11* show the calculation of carbon contents of annual increments and annual fellings based on the forest inventory data for two cases. In the first (calculation method 1), we multiply the upper and lower limits of m^3 o.b. values with the upper and lower limits of the m^3 u.b./m^3 o.b. conversion factor, then the upper and lower limits of air dry density are applied. From the upper and lower limts of air dry matter, we proceed with subtracting the water content of the upper and lower limits and finally multiply with the upper and lower limits of carbon content. In the second (calculation method 2), the conversion steps begin with m^3 o.b. values of the forest inventory by using conversion factors of Körner *et al*. (1993), which allows a direct conversion into t dm (*Table 10*). For the following conversion steps, the same uncertainty bands of the conversion factors as for calculation method 1 are applied.

In the first case, the mean carbon fixation of the annual increment of the AFI is 5.06 mio. t C/a. The share of coniferous wood is 3.79 mio. t C/a, whereas the carbon content of deciduous wood amounts to 1.27 mio. t C/a. The lower limit of carbon content of the annual increment is 3.97 mio. t C/a, and the upper limit is 6.151 mio. t C/a. In assuming a symmetrical uncertainty band, this is ±22%.

The carbon content of annual fellings of the AFI amounts to 3.22 mio. t C/a on average. The lower limit is 2.46 mio. t C/a, and the upper limit is 3.99 mio. t C/a. The resulting uncertainty band is therefore ±24%.

Calculation method 2 results in 6.32 mio. t C/a that are fixed on average by the annual increment. This is substantially more than in calculation method 1. The lower limit is 5.11 mio. t C/a and the upper limit is 7.53 mio. t C/a. The resulting uncertainty band is 20%, which is slightly smaller than calculation method 1.

[25] See for example, http://www.carnica-holz.at/wwg1_navigation.htm, http://www.schlagenhauf.ch/d_fachinfo03.html.

Table 10: Carbon contents of the annual increment and the annual fellings of the AFI, calculation method 1.

Schieler *et al.* (1996)	Austrian Forest Inventory				Carbon Flows			
	Original data							
	Uncertainty interval [± 10^3 m^3 o.b.]	Upper value [10^3 m^3 o.b.]	Lower value [10^3 m^3 o.b.]	Mean value 1986–1990 [10^3 m^3 o.b.]	**Lower limit of carbon flow** [10^3 t]	**Upper limit of carbon flow** [10^3 t]	**Average carbon flow** [10^3 t]	**Uncertainty band** [± %]
Annual increment								
Coniferous wood	512	26188	25164	25676	3004	4579	**3791**	**21**
Deciduous wood	188	5928	5552	5740	970	1572	**1271**	**24**
Total	552	31968	30864	**31416**	**3974**	**6151**	**5062**	**22**
Annual fellings								
Coniferous wood	643	16707	15421	16064	1841	2921	**2381**	**23**
Deciduous wood	243	4024	3538	3781	618	1067	**843**	**27**
Total	707	20552	19138	**19845**	**2459**	**3988**	**3224**	**24**

Table 11: Carbon contents of the annual increment and the annual fellings of the AFI, calculation method 2.
Sources: Schieler *et al*. (1996), IIASA.

Schieler *et al*. (1996)	Austrian Wood Inventory				Carbon Flows			
	Original data							
	Uncertainty interval [± 10^3 m^3 o.b.]	Upper value [10^3 m^3 o.b.]	Lower value [10^3 m^3 o.b.]	Mean value 1986-1990 [10^3 m^3 o.b.]	**Lower limit of carbon flow** [10^3 t]	**Upper limit of carbon flow** [10^3 t]	**Average carbon flow** [10^3 t]	**Uncertainty band** [± %]
Annual increment								
Coniferous wood	512	26188	25164	25676	3930	5759	**4845**	**20**
Deciduous wood	188	5928	5552	5740	1178	1772	**1475**	**22**
Total	552	31968	30864	**31416**	**5109**	**7531**	**6320**	**20**
Annual fellings								
Coniferous wood	643	16707	15421	16064	2409	3674	**3041**	**22**
Deciduous wood	243	4024	3538	3781	751	1203	**977**	**25**
Total	707	20552	19138	**19845**	**3160**	**4877**	**4018**	**23**

The average carbon content of the fellings using calculation method 2 is 4.02 mio. t C/a. The uncertainty band lies between 3.16 mio. t C/a and 4.88 mio. t C/a, which equals ±23%.

It is obvious, that the uncertainty bands of both calculation methods are about the same size. This was to be expected, since the uncertainty intervals of the individual conversion factors from (m^3 o.b.) to (m^3 u.b.) to (t air dry matter) to (t dry matter) of calculation method 1 are already considered in the m^3 o.b. to t dry matter conversion factors of Körner *et al*. (1993) in calculation method 2.

Quite contrary to that, the upper and lower limits and consequently the resulting mean values of the two calculation methods differ substantially. This mainly traces back to the different density values applied in the two approaches.

In conclusion, the results clearly confirm, that due to the large influence of the conversion factors, the chosen conversion steps dramatically influence the resulting size of carbon flows.

5.2.2 Carbon flows according to the wood balance

In section 5.1.2 we showed that the uncertainty of the Austrian wood balance must be at least ±7.3% to be consistently linked with the AFI. Therefore, we start calculating the uncertainty band of carbon flows by using the resulting upper and lower limits of the wood balance (*Table 12*).

To check for the carbon contents of individual wood flows of the Austrian wood balance, we apply the same conversion steps as we did for the forest inventory in calculation method 1. Since the wood balance splits domestic wood harvest into roundwood and fuelwood from forest areas and from non-forest areas, and data from the HEN (FMAF, 1991; 1992; 1993) further allows splitting these numbers into shares of coniferous and deciduous wood, we take the average aggregated density factors calculated for the shares of coniferous and deciduous wood of the forest inventory and also apply them to the individual items of the wood balance.

For example, in line 2 of *Table 12*, the chosen value for the aggregated conversion factor for the lower limit of density of deciduous wood is 0.65 t air dry matter/m^3 u.b. For coniferous wood the value is 0.45 t air dry matter/m^3 u.b. Based on these factors the air dry matter values are individually calculated, added up and the resulting sum is then divided by the aggregated m^3 u.b. mean value (line 1 in *Table 12*). This gives an aggregated lower limit of density of 0.48 t air dry matter/m^3 u.b. for the fellings according to the HEN. The same principle is deployed for the sub-items “roundwood”, “fuelwood” and “other wood from forest areas”, whereby for the sub-item “fuelwood” of the item “other wood from forest areas” the aggregated value of the sub-item “fuelwood” of the item “fellings” is used, as well as for the upper limits of the density factors (*Table 12*).

As a result, we obtain newly weighted density factors for each of the items of the wood balance. Due to a relatively high share of deciduous wood (48% against only 8.6% for the item roundwood), this results in a substantially higher density conversion factor for the aggregated item “fuelwood” (e.g., 0.55 t air dry matter/m^3 u.b. for the lower limit). The following steps are equal to the procedure described for the forest inventory.

In the case of the item “other wood from forest areas”, the assumption that the aforementioned conversion factors for aggregated wood flows also mirror the relation of species shares of wood from forest areas is considered to be plausible.

This is not the case for “wood from non-forest areas”. Here, a larger amount of deciduous wood from, for example, hedgerows, as a typical element of agricultural land, or park and alley trees as well as fruit trees, has to be accounted for (see Bittermann and Gerhold, 1995). Therefore, we also use the conversion factor 0.55 t air dry matter/m^3 u.b for the lower limit and 0.61 air dry matter/m^3 u.b for the upper limit.

The size of the carbon flows related to wood harvest on our so-called Level 1 are shown in *Table 12*.

5.2.2.1 Size of carbon flows

The mean carbon flow according to our calculations based on the Austrian wood balance is 3.81 mio. t C/a, the upper limit is 4.56 mio. t C/a and the lower limit is 3.06 mio. t C/a. The uncertainty band is thus approximately ±20%. If we compare these numbers with those of section 5.2, we can see that the average carbon flow is remarkably higher than the first calculation method of the forest inventory, and only slightly smaller than the second. [For additional comparison: Jonas (1997) reported 4.1 mio. t C/a, while Orthofer (1997) reported 5.2 mio. t C/a including 0.4 mio. t C/a other biofuels (bark and branches used for energy production).]

The average values of all three calculation methods lie in each other’s uncertainty band and the uncertainty bands clearly overlap. By combining all of the approaches, we end up with an average carbon flow of 3.67 mio. t C/a and an already large uncertainty of ±33%.

In combining the two calculation methods, which are built upon the same conversion factors, we obtain 3.51 mio. t C/a as the average and an uncertainty of ±30%.

5.2.3 The quality of the first-order approach

Weiss *et al*. (2000) calculated an uncertainty band of approximately ±18% for exploitation of the Austrian woods, thereby thoroughly building upon assumed probability density functions as far as possible. Therefore, their approach is more precise, if we compare it with our first-order approach that leads to uncertainty bands of ±20–24% for the separate calculations based on the AFI and the Austrian wood balance. The combined uncertainty of our approaches is even higher. Since the linkage of different statistics only allows for the limited application of probability density functions and heavily depends on a set of assumptions, a further reduction of uncertainty without any adaptation of the underlying statistics is certainly hard to achieve. Nevertheless, another step in this direction is done by Jonas (2001).

Table 12: Calculation of carbon contents of harvest of the Austrian wood balance.
Sources: Bittermann and Gerhold (1995), IIASA.

Bittermann and Gerhold (1995)		Austrian Wood Balance Original data								
	1989 [10^3 m^3 u.b.]	1990 [10^3 m^3 u.b.]	1991 [10^3 m^3 u.b.]	Mean value 1989–1991 [10^3 m^3 u.b.]	Lower uncertainty limit [10^3 m^3 u.b.]	Upper uncertainty limit [10^3 m^3 u.b.]	Lower limit of density [t adm/m^3 u.b.]	Lower limit of air dry matter [10^3 t adm]	Upper limit of density [t adm/m^3 u.b.]	Upper limit of air dry matter [10^3 t adm]
Domestic wood production fellings (HEN)	**13822**	**15711**	**11492**	**13675**	**12674**	**14676**	**0.48**	**6115**	**0.53**	**7788**
Deciduous wood	2381	2265	2023	2223	2060	2386	0.65	1339	0.74	1765
Coniferous wood	11441	13446	9469	11452	10614	12290	0.45	4776	0.49	6022
Roundwood	**11146**	**12939**	**9055**	**11047**	**10238**	**11855**	**0.47**	**4784**	**0.51**	**6065**
Deciduous wood	1019	1012	835	955	885	1025	0.65	576	0.74	759
Coniferous wood	10127	11927	8220	10091	9353	10830	0.45	4209	0.49	5307
Share of deciduous wood [%]	9.1	7.8	9.2	8.6						
Fuelwood	**2676**	**2772**	**2437**	**2628**	**2436**	**2821**	**0.55**	**1331**	**0.61**	**1722**
Deciduous wood	1362	1253	1188	1268	1175	1360	0.65	764	0.74	1007
Coniferous wood	1314	1519	1249	1361	1261	1460	0.45	567	0.49	716
Share of deciduous wood [%]	51	45	49	48						
Other wood from forest areas	**3809**	**3735**	**3479**	**3674**	**3405**	**3943**	**0.50**	**1701**	**0.55**	**2185**
Roundwood	2259	2046	1868	2058	1907	2208	0.46	877	0.51	1126
Fuelwood	1550	1689	1611	1617	1498	1735	0.55	824	0.61	1058
Total wood from forest areas	**17631**	**19446**	**14971**	**17349**	**16079**	**18619**	**0.49**	**7817**	**0.54**	**9972**
Other domestic wood supply (without recycled re-used wood)	**1225**	**1275**	**1358**	**1286**	**1192**	**1380**	**0.53**	**630**	**0.59**	**812**
Wood from non-forest areas	875	875	933	894	829	960	0.55	456	0.61	585
Chips from forest residues	350	400	425	392	363	420	0.48	174	0.54	227
Total Harvest (without recycled re-used wood)	**18856**	**20721**	**16329**	**18635**	**17271**	**19999**	**0.49**	**8447**	**0.54**	**10785**
Harvest without bark and wood from non-forest soils	**17981**	**19846**	**15396**	**17741**	**16442**	**19040**	**0.49**	**7991**	**0.54**	**10199**

Table 12: Continued.

Bittermann and Gerhold (1995)	Austrian Wood Balance Original data									
	1989 [10^3 m^3 u.b.]	1990 [10^3 m^3 u.b.]	1991 [10^3 m^3 u.b.]	Mean value 1989–1991 [10^3 m^3 u.b.]	Lower limit of dry matter [10^3 t dm]	Upper limit of dry matter [10^3 t dm]	Lower limit of carbon flow [10^3 t]	Upper limit of carbon flow [10^3 t]	Average carbon flow [10^3 t]	Uncertainty band [± %]
Domestic wood production fellings (HEN)	**13822**	**15711**	**11492**	**13675**	**5198**	**6853**	**2339**	**3481**	**2910**	**20**
Deciduous wood	2381	2265	2023	2223	1138	1554	512	789	651	21
Coniferous wood	11441	13446	9469	11452	4060	5300	1827	2692	2260	19
Roundwood	**11146**	**12939**	**9055**	**11047**	**4067**	**5338**	**1830**	**2711**	**2271**	**19**
Deciduous wood	1019	1012	835	955	489	668	220	339	280	21
Coniferous wood	1.127	11927	8220	10091	3577	4670	1610	2372	1991	19
Share of deciduous wood [%]	9.1	7.8	9.2	8.6						
Fuelwood	**2676**	**2772**	**2437**	**2628**	**1131**	**1516**	**509**	**770**	**640**	**20**
Deciduous wood	1362	1253	1188	1268	649	886	292	450	371	21
Coniferous wood	1314	1519	1249	1361	482	630	217	320	268	19
Share of deciduous wood [%]	51	45	49	48						
Other wood from forest areas	**3809**	**3735**	**3479**	**3674**	**1446**	**1922**	**651**	**977**	**814**	**20**
Roundwood	2259	2046	1868	2058	746	991	336	503	420	20
Fuelwood	1550	1689	1611	1617	700	931	315	473	394	20
Total wood from forest areas	**17631**	**19446**	**14971**	**17349**	**6644**	**8776**	**2990**	**4458**	**3724**	**20**
Other domestic wood supply (without recycled re-used wood)	**1225**	**1275**	**1358**	**1286**	**536**	**715**	**241**	**363**	**302**	**20**
Wood from non-forest areas	875	875	933	894	387	515	174	262	218	20
Chips from forest residues	350	400	425	392	148	200	67	101	84	21
Total Harvest (without recycled re-used wood)	**18856**	**20721**	**16329**	**18635**	**7180**	**9491**	**3231**	**4821**	**4026**	**20**
Harvest without bark and wood from non-forest soils	**17981**	**19846**	**15396**	**17741**	**6792**	**8975**	**3057**	**4559**	**3808**	**20**

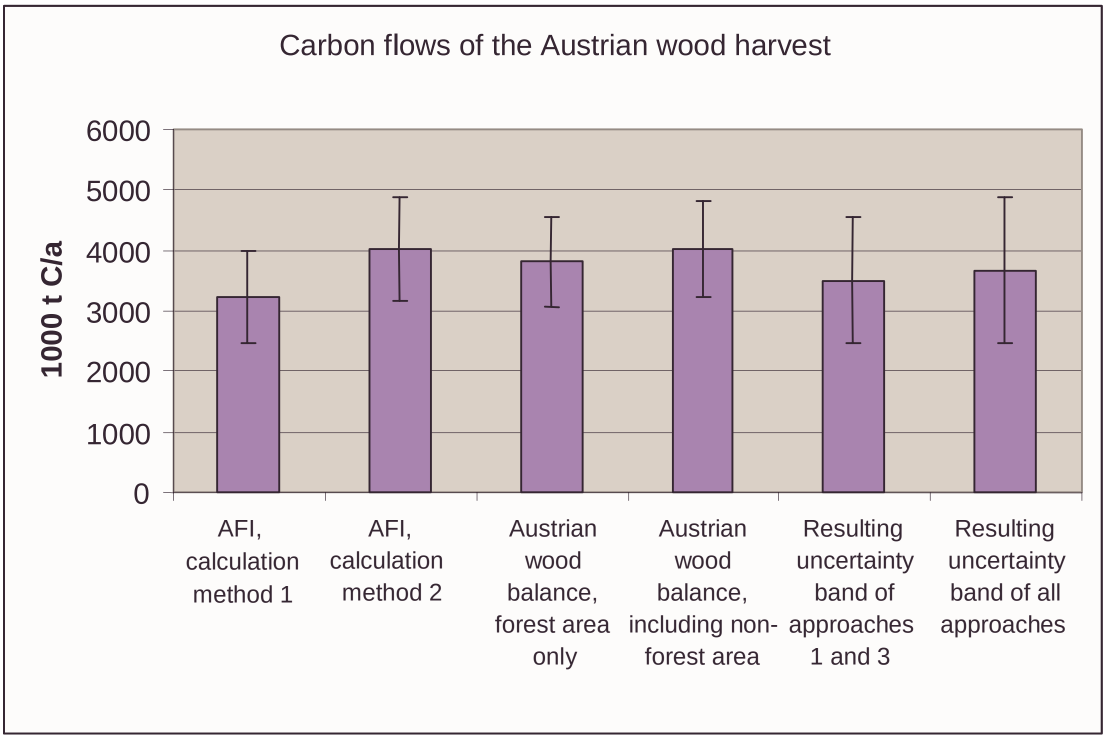


Figure 9: Carbon flows of the Austrian wood harvest. Source: IIASA.

5.3 Additional Remarks on Consistency of Carbon Flows To and From the PRODUCT and WASTE Modules

5.3.1 Material flow consistency

The previous sections emphasized the meaning of consistent wood flows as a prerequiste for consistent carbon flows. Accordingly, consistent material flows are seen as equally important for balancing other carbon flows, particularly in the PRODUCT and WASTE modules. Although Orthofer *et al*. (2001) set up a very detailed framework on the distinct carbon flows in this field, one should not neglect the studies on the material flow accounting of Austria, which have been conducted for many years by the Institute for Interdisciplinary Research and Education at the University of Vienna (Steurer, 1992; 1994; Hüttler *et al*., 1996; Schandl and Zangerl-Weisz, 1997; Payer *et al*., 1998). These studies on the MFA of Austria address basic problems of material accounting based on Austrian statistical data, which is why the main problems are repeated here for a better understanding in the context of carbon accounting, which is dealt with in detail by Jonas (2001) in particular.

5.3.2 Material flow analysis (MFA) of Austria

The aim of the MFA of Austria has been and is to check the feasibility of periodic national material flow accounting as well as its implementation into official statistics (Hüttler *et al*., 1996). Besides this main goal of reflecting material flows on a so-called macro (national) level, the consideration of a sectoral MFA on a meso level (branch oriented) was another goal. Meso level considerations can be done by using different approaches; the institutional and activity based criteria are discussed in detail by Hüttler *et al*. (1996).

Based on institutional criteria, material flow accounting is confronted with a lot of problems, among which are:

- One potential source of error is the cumulation of single enterprise material flows to aggregates in the industry-based statistics, leading to an overestimate of material flows in a distinct sector of the economy. This is because intrasectoral supply networks are not obvious in industry statistics. Sector-related production data is therefore characterized by double countings, which cannot be settled based only on industry statistics, but by a large amount of additional information.
- The statistics on industry and trade (*Industrie- und Gewerbestatistik) (*e.g., ACSO, 1991b,c; 1992b,c; 1993b,c) reports only material flows that are opposed by money flows. Therefore, material flows are not reported if they are not connected to money flows.
- If less than four enterprises are affected, information is not delivered due to confidentiality. The number of suppressed items has increased during the last few years.
- Declarations in value units must be transformed to mass units, which also needs to be done for quantity units.
- Commodities that are bought and delivered unchanged are not grasped by the raw and auxiliary material statistics (*Roh- und Hilfsstoffstatistik*).
- The raw and auxiliary material statistics do not report changes of stocks.
- The statistics being used for production purposes apply to commodity flows that are running through the economy. Investment goods like machines, vehicles, and buildings are therefore not considered.
- The production statistics do not report about residuals.
- Incompatibilities between input and output data (e.g., ACSO 1990; 1991a; 1992d) due to trade codes and survey units remain until the adaptation of the industry and production statistics to PRODCOM-codes[26] and the ÖNACE[27] classification have been done.
- The problems mentioned differ markedly between branches.
- The main problems in providing consistent branch balances are the self-supply as well as the double countings related to the industry and production statistics.

[26] PRODCOM is an abbreviation for Production Communautaire (Community production). It is the name of a Eurostat project, the corresponding survey and a product list. The survey looks at the production of approximately 5,700 products, which figure in what is known as the PRODCOM list. This list is compatible with the nomenclature of products used for foreign trade statistics called the Combined Nomenclature. The list of products covers most industrial goods with the exception of energy products and the output of the construction industry.

[27] ÖNACE is the Austrian version of the Statistical Systematics of the Economic Activities of the European Union (Nomenclature générale des Activités économiques dans les Communautés Européennes —NACE).

- The industry and trade statistics only cover the real asset production, whereas material flows of civil engineering, supply of electricity, trade, services, and private households are not taken into account.
- Although there are some accounts of business line material flows, which are oriented to institutional criteria (association statistics), none of these studies represents a consistent input-output balance of the total material flows of a distinct business line. These studies are called sector concepts.

For all these reasons it is clear that, instead of reinventing the wheel of material accounting but rather to focus on carbon accounting, IIASA decided to use the Institut für Interdisciplinäre Forschung und Fortbilding (IFF — Institute for Interdisciplinary Studies of Austrian Universities) material analysis for Austria as the basis for the top-down approach in meeting consistency for national material flows.

6 Conclusions

In general, one of the main outcomes of the underlying study is the fact that attempting to establish a full carbon budget with reduced uncertainties will induce new pretenses to official reported statistical data. None of the existing data sets was ever intended to serve as a basis for calculating carbon flows, nor was there a need to combine different reporting sets in a consistent fashion. Establishing a consistent full carbon budget requires a system based view that inherently carries the demand of destroying the walls between different reporting systems. Conversion factors should not be used incidentally, but must be chosen and reasoned very carefully by the indication of uncertainty intervals.

In analyzing the consistency of material flows on a national level one should be aware of the possible inconsistencies underlying sub-national reporting systems (that is, for example, the use of conversion factors, which do not show up in aggregated values).

6.1 Methodological Approach

1. FCA requires much greater expenditure compared to usually applied carbon accounting methodologies so far, for example, the IPCC guidelines, but clearly offers a lot of additional possibilities in achieving a consistent carbon budget.
2. FCA requires consistent material flows, at least on a so-called macro or national level. Exceptions exist for the application of emission factors, for example, for soils or production processes. The two main parameters for building the consistent material flow framework are the aspired level of detail and the referring availability of statistical data.
3. Data for national material flows is mainly based on statistical surveys provided by ACSO to which a lot of methodological problems are inherent.
4. Therefore, *assumptions* must be made on how to overcome the underlying problems and how to process this data. To assure verifiability, these assumptions must be clearly reported. To save work force, it is recommended to use the expertise of existing material flow approaches.

5. A consistent and balanced material flow framework is a prerequisite for calculating consistent carbon flows. Therefore, (if possible) a quantitative description of uncertainties underlying the material flow framework is of great importance for calculating the resulting uncertainties of carbon flows.
6. The Austrian case study shows that the increase of uncertainty follows a top-down approach, meaning that consistency of material flows can be achieved most easily on a national or so-called macro level. Establishing consistency of material flows on a more detailed or so-called meso level leads to a number of additional problems such as double counting errors or unreported data due to confidentiality.
7. Conversion factors are crucial for calculating a consistent carbon budget, leading to the conclusion that the selection procedure as well as the range of the conversion factors should be documented precisely. Moreover, building consistent conversion factors is a science in itself, but is usually restricted to available resources.
8. The number of required conversion steps to carbon flows is dependent upon the kind of material flow and the usually applied measurement units, and can range from one to up to five or even more, which is the case for wood flows for example. Each conversion step results in an increasing range of uncertainty, therefore aggregated conversion steps must be treated and documented very carefully.
9. It is very important to differentiate between original and already derived statistical data sources, and to check them on the not obviously perceivable integration of conversion factors.
10. Standardized conversion factors are a challenge to the future for FCA.

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List of Contacted Scientists and Experts

Mr. R. Alder: Austrian Central Statistical Office, Vienna, Austria

Mr. DI Eder: Proholz Austria.

Univ. Ass. Dr. Gautsch: Institute of Wood Science and Technology, University for Agricultural Sciences, Vienna, Austria.

Ms. DI Herzog: Forum for Forest, Board and Paper, Vienna, Austria.

Dr. Knieling: Federal Ministry of Agriculture and Forestry, Vienna, Austria.

Mr. Neumüller: Wood Science Austria/Arsenal, Vienna, Austria.

Dr. Teischinger: Federal Testing Institute for the Timber Industry, Higher Technical College (HTBLVA), Mödling, Austria.

Appendix

Table A1: Carbon flows into and out of the WASTE module (mio. t C/a). Source: Orthofer (1997).

WASTE MODULE			
Internal flows			
	Sewage sludge, Landfill		0.1
	Waste active, Compost		0.8
	Waste active, Landfill		1.0
	Waste active, Recycling		0.0
	Waste active, Waste water		0.5
	Waste water, Sewage sludge		0.1
AW_compost residuals		**0.4**	
	Animal food, Waste active		0.1
	Plant food, Waste active		0.3
WA_sewage sludge, biowaste, compost		**0.2**	
	Compost, Litter-humus-soil/fields		0.2
	Sewage sludge, Litter-humus-soil/fields		0.0
EW_incineration residuals		**0.2**	
	District heating, Waste inert		0.0
	Electricity production, Waste inert		0.1
	Industry, Waste inert		0.1
	Residential, Waste inert		0.0
	Self use, Waste inert		0.0
WE_waste for burning		**0.9**	
	Sewage sludge, Pool 1		0.0
	Waste active, Pool 1		0.9
IEW_waste imports		**0.0**	
	Surface water, Waste water		0.0
	Waste, Waste active		0.0
WIE_waste exports		**0.0**	
	Waste active, Waste		0.0
	Waste active, Surface water		0.0
WH_waste water		**0.5**	
	Waste active, Waste water		0.5
WL_landfill storage		**1.0**	
	Landfill		0.3
	Waste inert		0.7
WT_CO_2,CH_4 emissions		**1.7**	
	Compost		0.6
	Landfill		0.7
	Waste water		0.4
WP_recycled products		**0.0**	
	Recycling raw materials		0.0
PW_wastes		**3.3**	
	Food products, Waste active		0.2
	Human nutrition, Waste active		0.3
	Long-lived products, Waste inert		0.5
	Long-lived products, Waste active		1.1
	Production, Waste active		0.3
	Raw materials, Waste active		0.0
	Short-lived products, Waste active		0.9
Sum input			**3.9**
Sum output			**4.3**
Balance			**-0.4**

Table A2: Carbon flows into and out of the AGRO module (mio. t C/a).
Source: Orthofer (1997).

AGRO			
Internal flows			
	Animal food, Food	0.1	
	Animal pastures, Animal pool	0.0	
	Animal pastures, Manure pastures	0.1	
	Animal pool, Animal food	0.2	
	Animal pool, Animals	0.0	
	Animal stable, Animals pool	0.2	
	Animal stable, Manure stable	2.4	
	Feed, Animal pastures	0.4	
	Feed, Animal stable	4.8	
	Harvest, Biofuels	0.2	
	Harvest, Feed	4.9	
	Harvest, Plant food	1.6	
	Harvest, Raw materials	0.5	
	Manure pastures, Litter-humus-soil pastures	0.1	
	Manure stable, Litter-humus-soil fields	1.3	
	Manure stable, Litter-humus-soil meadows	1.1	
	Plant food, Food	1.3	
	Plant fields, harvest	4.5	
	Plant fields, Litter-humus-soil fields	2.2	
	Plant meadows, Harvest	2.3	
	Plant meadows, Litter-humus-soil meadows	4.7	
	Plant pastures, Harvest	0.4	
	Plant pastures, Litter-humus-soil pastures	8.8	
AW_compost residuals		**0.4**	
	AW_animal food waste active	0.1	
	AW_plant food waste active	0.3	
WA_sewage sludge, biowaste, compost		**0.2**	
	WA_compost litter-humus-soil fields	0.2	
	WA_sewage sludge litter-humus-soil fields	0.0	
AT_emissions		**20.8**	
	AT_Animal pastures	0.3	
	AT_Animal stable	2.2	
	AT_Litter-humus-soil fields	3.5	
	AT_Litter-humus-soil meadows	5.8	
	AT_Litter-humus-soil pastures	9.0	
	AT_Manure pastures	0.0	
	AT_Manure stable	0.0	
TA_net primary production		**22.9**	
	TA_plant fields	6.7	
	TA_plant meadows	7.0	
	TA_plant pastures	9.2	
AX_export		**0.8**	
	AX_Animal pool, Animals	0.0	
	AX_Feed, Feed	0.3	
	AX_Food, Food	0.5	
XA_import		**0.7**	
	XA_Animals, Animal pool	0.0	
	XA_Feed, Feed	0.3	
	XA_Food, Food	0.4	
AE_biomass		**0.2**	
	AE_Biofuels, Pool 1	0.2	
EA_biogenic waste		**0.0**	
	EA_Residential Litter-humus-soil pastures	0.0	
	EA_Traffic Litter-humus-soil pastures	0.0	
AP_products		**1.8**	
	AP_Food, Products	0.6	
	AP_Food, Raw materials	0.7	
	AP_Raw materials, Raw materials	0.5	
PA_fertilizer		**0.0**	
	PA_Fertilizer Litter-humus-soil fields	0.0	
AL_lithosphere		**0.0**	
	AL_Litter-humus-soil fields	0.0	
	AL_Litter-humus-soil meadows	0.0	
	AL_Litter-humus-soil pastures	0.0	
Sum input			**23.8**
Sum output			**24.0**
Balance			**-0.2**

Table A3: Carbon flows into and out of the FORESTRY module (mio. t C/a). Source: Orthofer (1997).

FORESTRY MODULE			
Internal flows			
	Harvest, Roundwood	2.1	
	Harvest, Fuelwood	2.7	
	Harvest, Other biofuels	0.4	
	Litter managed, Humus soils managed	6.9	
	Litter unmanaged, Humus soils unmanaged	1.2	
	Trees managed, Harvest	5.2	
	Trees managed, Litter managed	15.6	
	Trees unmanaged, Litter unmanaged	2.5	
TF_net primary production		**24.6**	
	TF_Trees managed	22.0	
	TF_Trees unmanaged	2.6	
FT_emissions		**14.1**	
	FT_Humus soils managed	4.8	
	FT_Humus soils unmanaged	1.1	
	FT_Litter managed	6.9	
	FT_Litter unmanaged	1.3	
FE_fuelwood		**3.1**	
	FE_Fuelwood, Pool 1	2.7	
	FE_Other biofuels, Pool 1	0.4	
FX_fuelwood		**0.0**	
	FX_Fuelwood, Fuelwood	0.0	
XF_fuelwood		**0.0**	
	XF_Fuelwood, Fuelwood	0.0	
FL_lithosphere		**0.0**	
	FL_Humus soils managed	0.0	
	FL_Humus soils unmanaged	0.0	
LF_uptake		**0.0**	
	LF_Humus soils managed	0.0	
	LF_Humus soils unmanaged	0.0	
FP_roundwood		**2.1**	
	Roundwood, Products	0.0	
	Roundwood, Raw materials	2.1	
Sum input			**24.6**
Sum output			**19.3**
Balance			**5.3**

Table A4: Carbon flows into and out of the ENERGY module (mio. t C/a). Source: Orthofer (1997).

ENERGY MODULE			
Internal flows			
	Coke production, Pool 2	1.4	
	Gas production, Pool 2	0.5	
	Pool 1, Coke production	1.8	
	Pool 1, Gas production	0.5	
	Pool 1, Pool 2	11.2	
	Pool 1, Refinery	7.5	
	Pool 1, Stock	0.8	
	Pool 1, Fossil fuels	0.4	
	Pool 1, District heating	0.8	
	Pool 2, Electricity production	3.3	
	Pool 2, Grid losses	0.0	
	Pool 2,Non-energetic use	1.4	
	Pool 2, Pool 3	14.2	
	Pool 2, Self use	0.6	
	Pool 3, Industry	3.8	
	Pool 3, Residential	6.4	
	Pool 3, Traffic	4.0	
	Refinery, Pool 2	7.2	
	Stock, Pool 1	0.5	
AE_biomass		**0.2**	
	AE_Biofuels, Pool 1	0.2	
EA_biogenic waste		**0.0**	
	EA_Residential, Litter-humus-soil pastures	0.0	
	EA_Traffic, Litter-humus-soil pastures	0.0	
ET_emissions		**19.8**	
	ET_Coke production	0.4	
	ET_District heating	0.8	
	ET_Electricity production	3.2	
	ET_Gas production	0.0	
	ET_Grid losses	0.0	
	ET_Industry atmo	3.7	
	ET_Non-energetic use	0.4	
	ET_Refinery	0.3	
	ET_Residential	6.4	
	ET_Self use	0.6	
	ET_Traffic	4.0	
EW_incineration residuals		**0.2**	
	EW_District heating, Waste inert	0.0	
	EW_Electricity production, Waste inert	0.1	
	EW_Industry, Waste inert	0.1	
	EW_Residential, Waste inert	0.0	
	EW_Self use, Waste inert	0.0	
EP_raw oil, gas, bitumen, coal		**1.0**	
	Non-energetic use, Products	0.2	
	Non-energetic use, Raw materials	0.8	
FE_wood		**3.1**	
	FE_Fuelwood, Pool 1	2.7	
	FE_Other biofuels, Pool 1	0.4	
XE_fossil fuels		**15.0**	
	XE_Fossil fuels, Pool 1	15.0	
LE_fossil fuels		**2.5**	
	LE_Fossil fuels, Pool 1	2.5	
WE_waste for burning		**0.9**	
	WE_Sewage sludge, Pool 1	0.0	
	WE_Waste active, Pool 1	0.9	
Sum input			**21.7**
Sum output			**21.0**
Balance			**0.7**

Table A5: Conversion of m^3 o.b. into m^3 u.b.

Author	Object	Conversion factor m^3 u.b./m^3 o.b.
Bittermann and Gerhold (1995)	Timber	approximately 0.89
Jonas (1997)	Coniferous timber	0.8[a]
Jonas (1997)	Deciduous timber	0.8[a]
Schwaiger (1999)	Timber	0.7
Mean		0.795
Uncertainty interval (±%)		11.95

[a] This factor is derived from expert's knowledge, i.e., Dr. Knieling, Federal Ministry of Agriculture and Forestry; Jonas and Schidler (1996); and Dr. Wakolbinger, Federal Austrian Forests Inc.

Table A6: Conversion of m^3 o.b. gross volume into m^3 u.b.

Author	Object	Conversion factor m^3 pure wood/m^3 loose volume (fuelwood)
ACSO (1998; 1999)	Fuelwood (old values[a])	0.694
FMAF (1996)[b]	Fuelwood	0.64
ACSO (1998; 1999)	Chips, Sawn wood residues, Chips from forest residues (old values[a])	0.35
ACSO (1998; 1999)	Bark (old values[a])	0.33
FMAF (1996)[b]	Coniferous wood	0.68
FMAF (1996)[b]	Deciduous wood	0.63
Mean fuelwood		0.667
Uncertainty interval (± %)		4.0

[a] The term "old values" indicates that these values have been used for energy reporting by ACSO until the end of 1998.
[b] Recommended by the HEN questionnaire.

Table A7: Conversion of m^3 u.b. gross volume into m^3 u.b., into m^3 o.b. respectively.

Author	Object	Conversion factor m^3 pure wood/m^3 loose volume (fuelwood) without bark
FMAF (1991)	Pulpwood	0.7[a]
		Conversion factor m^3 pure wood/m^3 loose volume (fuelwood) with bark
FMAF (1991)	Fuelwood	0.7

[a] The value was 0.8 until 1987.

Table A8: Conversion of 1 t of wood with bark into m^3 u.b.

Author	**Object**	**Conversion factor m^3 u.b./t o.b.**
FMAF (1996)[a]	Spruce	2.11
FMAF (1996)[a]	Fir	1.75
FMAF (1996)[a]	Pine	1.75
FMAF (1996)[a]	Beech	1.42

[a] Recommended by the HEN questionnaire.

Table A9: Conversion of m^3 o.b. into t dry matter.

Author	**Object**	**Conversion factor t dm/m^3 o.b.**
Körner *et al*. (1993)	Mean for coniferous wood[a]	0.41
Körner *et al*. (1993)	Mean for deciduous wood[b]	0.52
Körner *et al*. (1993)	Spruce	0.39
Körner *et al*. (1993)	Fir	0.37
Körner *et al*. (1993)	Pine	0.42
Körner *et al*. (1993)	Larch	0.47
Körner *et al*. (1993)	Beech	0.56
Körner *et al*. (1993)	Oak	0.57
Körner *et al*. (1993)	Ash	0.57
Körner *et al*. (1993)	Maple	0.54
Körner *et al*. (1993)	Elm	0.46
Körner *et al*. (1993)	Birch	0.51
Körner *et al*. (1993)	Alder	0.43
Jonas (1997)	Coniferous forest	0.42
Jonas (1997)	Deciduous forest	0.58

[a] Equal parts of spruce, fir, pine, and larch.
[b] Equal parts of beech, oak, ash, maple, elm, birch, and alder.

Table A10: Conversion of m^3 loose volume (fuelwood) into t air dry matter (wood density).

Author	Object	Conversion factor t air dry matter/ m^3 loose volume (fuelwood)
Herzog (1998)	Fuelwood	0.63
Herzog (1998)	Wood chips	0.30
Herzog (1998)	Sawdust	0.26
ACSO (1998; 1999)	Fuelwood (old values[a])	0.555
ACSO (1998; 1999)	Chips, Sawn wood residues, Chips from forest residues (old values)	0.80
ACSO (1998; 1999)	Bark (old values)	0.841
ACSO (1998; 1999)	Wood briquettes (old values)	
ACSO (1998; 1999)	Sawn chips (new values)[c]	0.27[b]
ACSO (1998; 1999)	Byproduct sawn wood residues (offcut), Sawn wood residues (new values)[c]	0.48[b]
ACSO (1998; 1999)	Byproduct sawdust (new values)[c]	0.23[b]
ACSO (1998; 1999)	Byproduct planing shavings (new values)[c]	0.095[b]
ACSO (1998; 1999)	Bark (new values)[c]	0.32[b]
ACSO (1998; 1999)	Chips from forest residues (new values)[c]	0.22[b]
Mean	Fuelwood	0.593
Uncertainty interval	Fuelwood	6.3

[a] The term “old values” indicates that these values have been used for energy reporting by ACSO until the end of 1998.
[b] In this case it is m^3 loose volume (chips).
[c] ÖNORM M9466 has been taken into account by the authors.

Table A11: Conversion of m^3 u.b. (m^3 pure wood) into t air dry matter and total dry matter respectively.

Author	Object	Conversion factor t dm[a]/m^3 u.b.	Conversion factor t fw[b]/m^3 u.b.
Österreichisches Normungsinstitut (1998)	Spruce	0.41	
Wiener Börsenkammer (1985)	Spruce	0.427	
Sell (1997)	Spruce	0.40–0.43	0.43–0.47
Österreichisches Normungsinstitut (1998)	Fir	0.41	
Wiener Börsenkammer (1985)	Fir	0.427	
Sell (1997)	Fir	0.40–0.45	0.43–0.48
Österreichisches Normungsinstitut (1998)	Pine	0.51,[c] 0.56[d]	
Wiener Börsenkammer (1985)	Pine	0.51	
Sell (1997)	Pine	0.46–0.51	0.51–0.55
Österreichisches Normungsinstitut (1998)	Larch	0.55	
Wiener Börsenkammer (1985)	Larch	0.545	
Sell (1997)	Larch	0.50–0.58	0.54–0.62
Österreichisches Normungsinstitut (1998)	Beech	0.68	
Wiener Börsenkammer (1985)	Beech	0.65	
Sell (1997)	Beech	0.64–0.72	0.70–0.79
Österreichisches Normungsinstitut (1998)	Hornbeam	0.75	
Wiener Börsenkammer (1985)	Hornbeam	0.68	
Sell (1997)	Hornbeam	0.70–0.79	0.75–0.86
Österreichisches Normungsinstitut (1998)	Oak	0.67	
Wiener Börsenkammer (1985)	Oak	0.63	
Sell (1997)	Oak	0.60–0.70	0.65–0.76
Österreichisches Normungsinstitut (1998)	Ash	0.67	
Wiener Börsenkammer (1985)	Ash	0.65	
Sell (1997)	Ash	0.64–0.70	0.68–0.76
Österreichisches Normungsinstitut (1998)	Maple	0.59	
Sell (1997)	Maple	0.57–0.62	0.61–0.66
Österreichisches Normungsinstitut (1998)	Elm	0.64	
Sell (1997)	Elm	0.54–0.64	0.59–0.68
Österreichisches Normungsinstitut (1998)	Birch	0.64	
Wiener Börsenkammer (1985)	Birch	0.585	
Sell (1997)	Birch	0.61–0.68	0.65–0.73
Österreichisches Normungsinstitut (1998)	Alder	0.49	
Wiener Börsenkammer (1985)	Alder	0.48	
Sell (1997)	Alder	0.46–0.53	0.49–0.57
Steurer (1994)	Harvested wood		0.86
Hüttler *et al*. (1996)	Harvested wood		0.75
UNECE/FAO (1994)	Coniferous sawlogs		0.7
UNECE/FAO (1994)	Non-coniferous sawlogs		0.8
UNECE/FAO (1994)	Coniferous fuelwood		0.625[e]
UNECE/FAO (1994)	Non-coniferous fuelwood		0.697[f]
ACSO (1998, 1999)	Fuelwood (old values[g])		0.807
ACSO (1998, 1999)	Fuelwood (new values)		0.6575
ACSO (1998, 1999)	Sawn chips (new values[h])		0.770
ACSO (1998, 1999)	Byproduct sawn wood residues (officut), Sawn wood residues (new values)		0.800
ACSO (1998, 1999)	Byproduct sawdust (new values)		0.750
ACSO (1998, 1999)	Byproduct planing shavings (new values)		0.480
ACSO (1998, 1999)	Bark (new values)		0.960
ACSO (1998, 1999)	Chips from forest residues		0.600

[a] Moisture content equals zero. [b] Moisture content equals 12–15%. [c] White pine. [d] Black pine. [e] Derived, 0.7 m^3 u.b. equals 0.4375 t. [f] Derived, 0.65 m^3 u.b. equals 0.4875 t. [g] The term "old values" indicates that these values have been used for energy reporting by ACSO until the end of 1998. [h] ÖNORM M9466 has been taken into account by the authors.

Table A12: Calculation of mean and uncertainty of reported density values.

	Object	**Conversion factor t dm[a]/m^3 u.b.**	**Conversion factor t adm[b]/m^3 u.b.**
Mean	Spruce	0.415	0.45
Uncertainty interval (%)	Spruce	**3.6**	**4.4**
Mean	Fir	0.425	0.455
Uncertainty interval (%)	Fir	**5.9**	**5.5**
Mean	Pine	0.51	0.53
Uncertainty interval (%)	Pine	**9.8**	**3.8**
Mean	Larch	0.54	0.58
Uncertainty interval (%)	Larch	**7.4**	**6.9**
Mean	Beech	0.68	0.745
Uncertainty interval (%)	Beech	**5.9**	**6.0**
Mean	Hornbeam	0.735	0.805
Uncertainty interval (%)	Hornbeam	**7.5**	**6.8**
Mean	Oak	0.65	0.705
Uncertainty interval (%)	Oak	**7.7**	**7.8**
Mean	Ash	0.67	0.72
Uncertainty interval (%)	Ash	**4.5**	**5.6**
Mean	Maple	0.595	0.635
Uncertainty interval (%)	Maple	**4.2**	**3.9**
Mean	Elm	0.59	0.635
Uncertainty interval (%)	Elm	**8.5**	**7.1**
Mean	Birch	0.633	0.69
Uncertainty interval (%)	Birch	**7.5**	**5.8**
Mean	Alder	0.495	0.53
Uncertainty interval (%)	Alder	**7.1**	**7.5**
Mean UNECE/FAO (1994)	Sawlogs		0.75
Uncertainty interval (%)	Sawlogs		**6.7**
Mean	Fuelwood		0.716
Uncertainty interval (%)	Fuelwood		**12.7**
			0.091

[a] Moisture content equals zero.
[b] Moisture content equals 12–15%, if there is no value in the column then the moisture content of wood is reported.

Table A13: Moisture contents of wood.

Author	Object	Moisture content of wood (%)
IPCC (1995; 1996a,b)	Fuelwood (air dry)	20[a]
IPCC (1995; 1996a,b)	Wet wood, freshly cut	40[a]
IPCC (1995; 1996a,b)	Air-dry wood, humid zone	20[a]
IPCC (1995; 1996a,b)	Oven dry wood	0[a]
ACSO (1998; 1999)	Fuelwood (old values[b])	15
ACSO (1998; 1999)	Fuelwood (new values)	20
ACSO (1998; 1999)	Chips, Sawn wood residues, Chips from forest residues (old values)	15
ACSO (1998; 1999)	Bark (old values)	50
ACSO (1998; 1999)	Wood briquettes (old values)	9
ACSO (1998; 1999)	Sawn chips (new values)	45
ACSO (1998; 1999)	Byproduct sawn wood residues (offcut), Sawn wood residues (new values)	37.5
ACSO (1998; 1999)	Byproduct sawdust (new values)	45
ACSO (1998; 1999)	Byproduct planing shavings (new values)	10
ACSO (1998; 1999)	Bark (new values)	50
ACSO (1998; 1999)	Chips from forest residues	25
Mean value fuelwood		17.5
Uncertainty interval (%)		2.5
Uncertainty interval (%)		**14.3**

[a] Moisture content weight basis.
[b] The term "old values" indicates that these values have been used for energy reporting by ACSO until the end of 1998.

Table A14: Carbon contents of total dry wood.

Author	Object	Conversion factor t C/t dm
Jonas (1997)	Coniferous forest	0.45
Jonas (1997)	Deciduous forest	0.45
Körner *et al*. (1993)	Mean for coniferous wood[a]	0.45
Körner *et al*. (1993)	Mean for deciduous wood[b]	0.45
Österreichisches Normungsinstitut (1998)	Coniferous wood	0.508[c]
Österreichisches Normungsinstitut (1998)	Deciduous wood	0.492[c]
Wimmer and Halbwachs (1992)	Wood	0.47
Woodwell and Whittaker in Körner *et al*. (1993)		0.47
Mean		0.479
Uncertainty interval		6.1

[a] Equal parts of spruce, fir, pine, and larch.
[b] Equal parts of beech, oak, ash, maple, elm, birch, and alder.
[c] Strictly speaking applies only for beech and oak.

Table A15: Conversion of t C stemwood into m^3 o.b.

Author	Object	Conversion factor t C stemwood/m^3 o.b.
Jonas (1997)	Coniferous forest	0.19[a]
Jonas (1997)	Deciduous forest	0.26[b]
Jonas (1997)	Area weighted mean for Austria	0.206
This study, based on Jonas (1997)	Growing stock weighted mean for Austria	0.202
Körner *et al*. (1993)	Mean for coniferous wood[c]	0.185
Körner *et al*. (1993)	Mean for deciduous wood[d]	0.234
Körner *et al*. (1993)	Spruce	0.176
Körner *et al*. (1993)	Fir	0.167
Körner *et al*. (1993)	Pine	0.189
Körner *et al*. (1993)	Larch	0.212
Körner *et al*. (1993)	Beech	0.252
Körner *et al*. (1993)	Oak	0.257
Körner *et al*. (1993)	Ash	0.257
Körner *et al*. (1993)	Maple	0.243
Körner *et al*. (1993)	Elm	0.207
Körner *et al*. (1993)	Birch	0.230
Körner *et al*. (1993)	Alder	0.194

[a] Strictly speaking applies only for spruce and pine.
[b] Strictly speaking applies only for beech and oak.
[c] Equal parts of spruce, fir, pine, and larch.
[d] Equal parts of beech, oak, ash, maple, elm, birch, and alder.

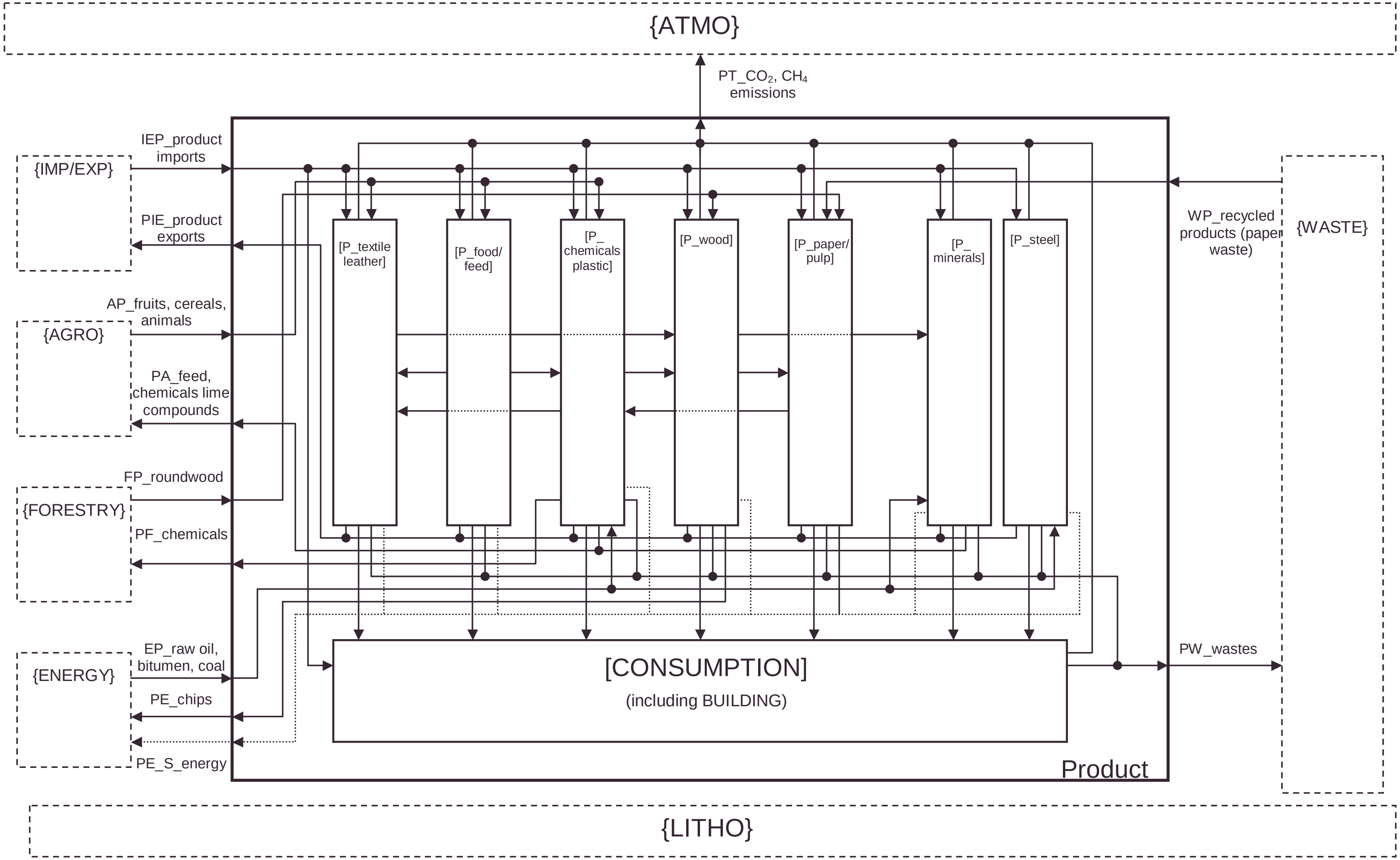
Table A16: Net calorific values of wood.

Author	Object	Typical net calorific value (rough approximations) MJ/kg, GJ/t
IPCC (1995; 1996a,b)	Fuelwood (air dry)	15
IPCC (1995; 1996a,b)	Wet wood, freshly cut	10.9
IPCC (1995; 1996a,b)	Air dry wood, humid zone	15.5
IPCC (1995; 1996a,b)	Oven dry wood	20
Österreichisches Normungsinstitut (1998)	Coniferous wood	19.0,[a] 20.4[b]
Österreichisches Normungsinstitut (1998)	Deciduous wood	18.0,[a] 19.3[b]
AIER (1996)	Fuelwood	15.5
ACSO (1998; 1999)	Fuelwood (old values[c])	15.5
ACSO (1998; 1999)	Fuelwood (new values)	14.35
ACSO (1998; 1999)	Chips, Sawn wood residues, Chips from forest residues (old values)	15.5
ACSO (1998; 1999)	Bark (old values)	8.5
ACSO (1998; 1999)	Wood briquettes (old values)	16.6
ACSO (1998; 1999)	Sawn chips (new values)	9.4
ACSO (1998; 1999)	Byproduct sawn wood residues (offcut), sawn wood residues (new values)	10.7
ACSO (1998; 1999)	Byproduct sawdust (new values)	9.3
ACSO (1998; 1999)	Byproduct planing shavings (new values)	16.8
ACSO (1998; 1999)	Bark (new values)	8.3
ACSO (1998; 1999)	Chips from forest residues	13.5
Mean	Fuelwood	14.9
Uncertainty interval		**3.9**

[a] Calorific value.
[b] Gross calorific value.
[c] The term "old values" indicates that these values have been used for energy reporting by ACSO until the end of 1998.

Table A17: Annual fellings by share of tree species reported by the AFI (Schieler *et al.*, 1996).

Species	Share of total fellings (%)
CONIFEROUS	
Spruce	60.8
Fir	5.4
Larch	5.1
White pine	9
Black pine	0.5
Pinus mugo	0.1
Total coniferous wood	**80.9**
DECIDUOUS	
Beech	8.1
Oak	2.3
Hornbeam	1
Ash	1.1
Maple	0.7
Elm	0.4
Chestnut	0
Robinie	0.3
Sorbus and Prunus	0.3
Birch	1.2
Black alder	0.8
White alder	1
Lime	0.2
Rest	1.8
Total deciduous wood	**19.1**



1) P1 to P15 serve as shortages for material fluxes, which will be described in detail in a future database.

Figure A1: Level 3 of the Product Module. Source: IIASA, IIE.

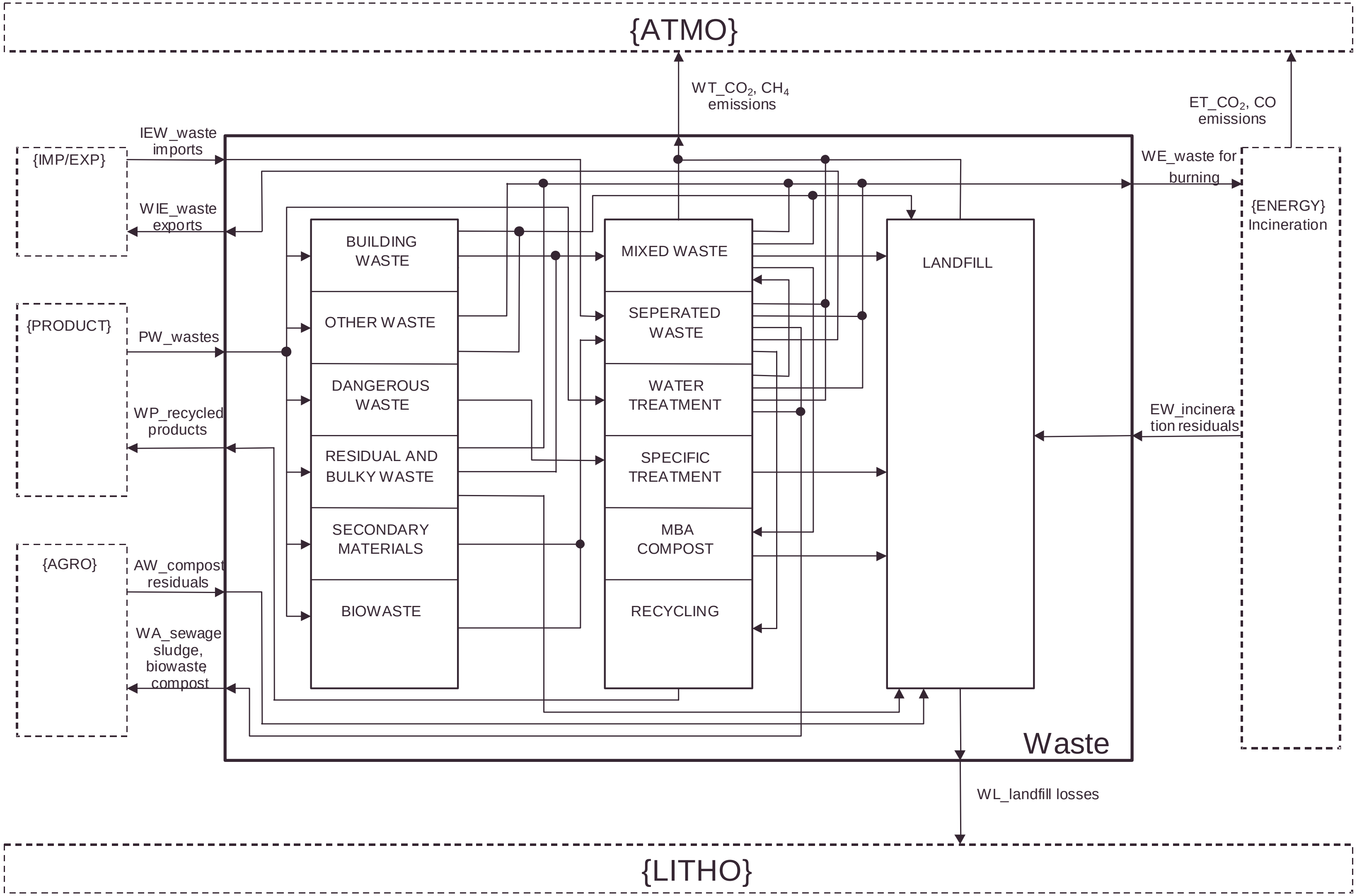


Figure A2: Level 3 of the Waste Module. Source: IIASA, IIE.

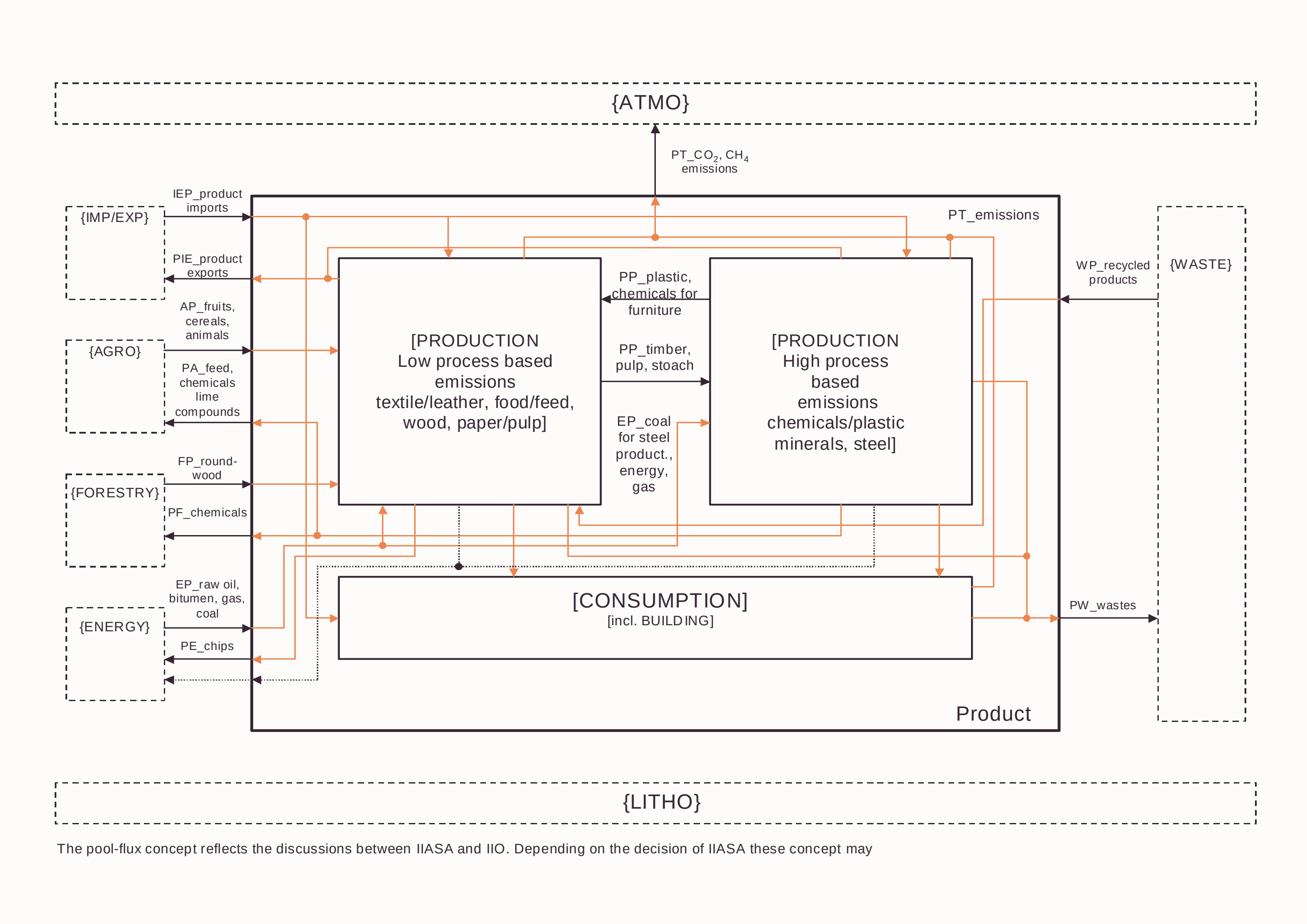


Figure A3: Level 2 of the Product Module. Source: IIASA, IIE.

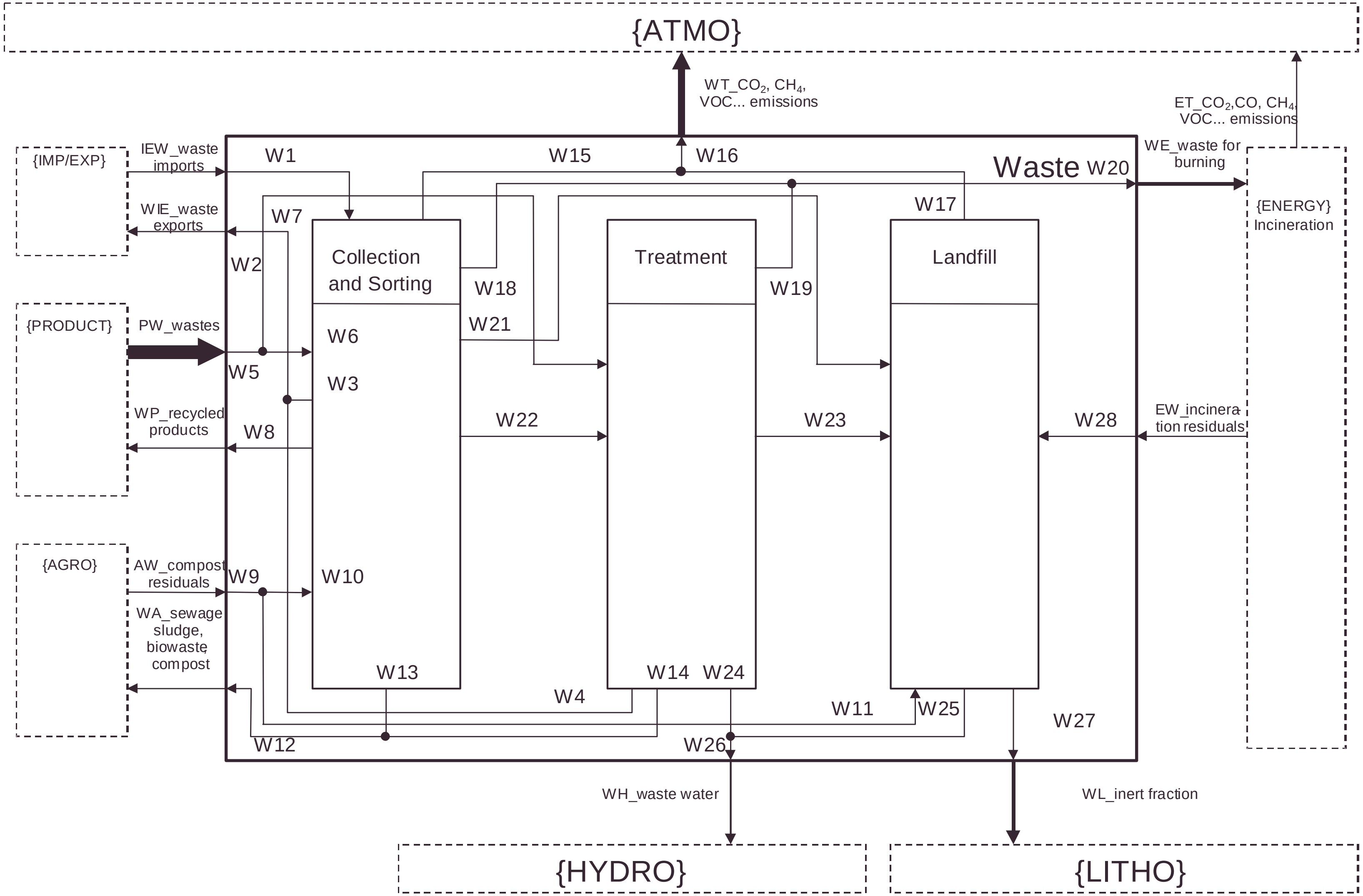


Figure A4: Level 2 of the Waste Module. Source: IIASA, IIE.