R E P O R T

The Austrian Carbon Balance Model (ACBM)

Final Project Report Annex

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ABSTRACT

This report is the Annex of the Austrian Carbon Balance Model (ACBM) project final report. It serves as supplementary material. It contains the documentation about the nomenclature (Annex 1), supplementary information to the five ACBM modules (Annex 2-6), a description and a instruction manual of the model (Annex 7) and information about the Austrian Carbon Database project (ACDb) (Annex 8).

ZUSAMMENFASSUNG

Dieser Bericht ist der Annex zum Austrian Carbon Balance Model (ACBM) Projekt Endbericht. Der Bericht dient als ergänzendes Material. Er beinhaltet die Dokumentation der verwendeten Nomenklatur (Annex 1), ergänzende Informationen zu den einzelnen Modulen des Models (Annex 2-6), eine Beschreibung der Models und Bedienungsanleitung (Annex 7) und beinhaltet Informationen über das Projekt Austrian Carbon Database (ACDb) (Annex 8).

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Annex 1

Nomenclature

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Annex 1 ACBM Nomenclature

In order to ensure homogeneous work among the three project partners, a strict nomenclature has been agreed upon. The ACBM nomenclature serves as a “common language” and ensures a smooth exchange of model concepts and equations between the project partners. This nomenclature contains the following model elements.

A 1-1 Modules

Modules are identified with a short word in capitals in brackets. For all model elements (such as flows and pools) the relevant modules are abbreviated with a one capital letter followed by an underscore (Table A 1-1).

Table A 1-1: Basic module nomenclature

Carbon subsystem	Module	Abbreviation
Agriculture	{AGRO}	A_
Energy Transformation and Use	{ENERGY}	E_
Forestry	{FOREST}	F_
Production and Consumption	{PROD}	P_
Waste	{WASTE}	W_
Atmosphere	{ATMO}	T_
Lithosphere	{LITHO}	L_
Import/Export of Goods	{IMPEXP}	X_

A 1-1.1 Pools

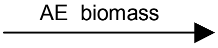
A pool is a carbon storage. It is non-dynamic in a sense that it has a certain value at any given time. Pools are identified in the diagrams as rectangles. Pool names consist of the respective module abbreviation, and the pool name in capital letters. Standard units for pools are Megatons Carbon (MtC).

Example: *“A_GRASSLAND” is the pool of carbon biomass in grassland vegetation biomass on in the module {AGRO}.*

A 1-1.2 Flows

Flows are the central element of the dynamic model. They are transfers of carbon between pools over time. Flows are dynamic in nature, i.e. with ∆t=0 all flows become zero. Flows are identified in the diagrams as arrows. Flows can occur within a module or between modules. Flow names consist of the abbreviation of the origin and the destination modules and the name of the flow in small letters. Flows within a module have a double module abbreviation. Standard units for flows are Megatons Carbon per year (MtC.yr^{-1}).

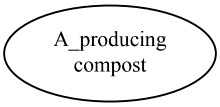
Example: *“AA_harvest from house gardens” is a flow that occurs within the {AGRO} module (“AA_”). It refers to the flow of carbon from the housegarden vegetation (A_HOUSEGARDEN) to the dispatcher (see below) “A_plants for self consumption”.*



A 1-1.3 Processes

Processes are model elements in which a carbon input is transformed into different carbon outputs (such as during composting of biogenic materials). The nature of the output is determined by the kind and duration of the process. A process has no storage of carbon. Processes are identified in the diagrams as ellipses. Process names consist of the abbreviation of the module and the process name in small letters. Standard units for processes are Megatons Carbon per year (MtC.a-1).

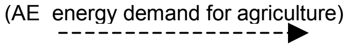
Example: *"A_producing compost" is a process in the module {AGRO} in which carbon from domestic biowaste (the flow "AA_waste from self consumption") is transformed into CO_2 and CH_4 that is then released into the atmosphere (i.e. the flow "AT_CO_2 and CH_4 from compost") and into compost that is used for soil amendment (AA_compost).*



A 1-1.4 Control Variables

Control variables contain information that is important for the control of flows. Control variables do not refer to any carbon "currency", but they are needed to determine or quantify carbon flows. Processes are identified in the diagrams as dotted arrows. Control variable names consist of the abbreviation of the origin and the destination modules and the name of the control variable in small letters in brackets. As control variables might refer to a variety of parameters, there are no standard units. However, all units will refer to yearly rates of the relevant parameters.

Example: *"(AE_energy demand for agriculture)" contains information about the energy demand (in PJ per year) of agriculture in the {AGRO} module that has to be satisfied from the energy supply in the {ENERGY} module.*



A 1-1.5 Dispatchers

Dispatchers are auxiliary elements that are used for summarizing carbon inflows and to relate them to carbon outflows. Its function is similar to a traffic node where incoming and outgoing flows are distributed and balanced; in- and outputs have to be equal. Dispatchers are identified in the diagrams as hexagons. Dispatchers do not "contain" carbon pools but are usually summarized in order to validate the flows. The standard units of dispatchers are Megatons Carbon in one year (MtC.a-1). Dispatcher names consist of the module abbreviation and the name in small letters.

Example: *"A_harvest plants" is a dispatcher in the {AGRO} module that summarizes carbon inputs from harvested plant biomass (the flow "AA_harvest from cereals, crops and fruits") and dispatches it into an output of energy biomass (the flow "AE_biomass for heating"), raw materials for production ("AP_harvest from plants") and usage for feed and bedding ("AA_feed and bedding from harvest").*

Annex 2

ACBM Modul
AGRO

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A 2-1 Introduction

In real-world systems, many parameters need to be assessed. This requires tools for the enhancement of user-friendliness in data collection and organization.

"Data can become information if we know the process involved. Information can become knowledge if we see the system that is operating. But knowledge only becomes wisdom when we can see how any system must change, and can deal with that reality" (Allen 1994).

To build a model which gives a transparent view of the "real-world" is a difficult task. If you build the model independently, without an eye on the available data, it would hardly become a sophisticated tool for prediction into the future. Such a prediction of a mathematical model, which works with statistical data can be no better than the data used *(Fearn and Smith 1986*). Statistical data about Austria's agricultural production are very carefully maintained and evaluated. Therefore they can serve as a solid basis for model calculations. Due to these reasons our modeling concept is based both on a search for available data and on a study of the interaction between different compartments. Another crucial point is to build a model as simple as possible and as complex as needed, because the number of variables and parameters must be manageable and the behavior of the model must be capable of being fully explored at any point in time *(Grimm 1994*). To reach this goal we have agreed that only flows exceeding 0.1 Megatons Carbon per year (MtC/yr) are taken into account. Nevertheless, if available, not only aggregated model input data, but the original marginal subclasses combined within them are recorded in the background, e.g. the very detailed data set about all varieties of agricultural plant production.

The module {AGRO} is subdivided into three main parts, the VEGETATION, the HUSBANDRY and the SOIL system.

Vegetation

Within the VEGETATION part of the module five categories are represented:
- extensively cultivated grassland
- intensively cultivated grassland
- cereals, crops, fruits, vineyards
- house gardens
- other vegetation (e.g. wind protection belts, tree nurseries).

Distinguishing between the different types of vegetation allows to simulate the influence of changes in the cropping systems and land-use change on carbon dynamics. This strategy facilitates, for example, to analyze the influence of a conversion from intensive to extensive agricultural policy. Biomass removed from arable land (*AA_harvest from cereals, crops, fruits and others*) is guided into *A_harvest plants*, a dispatcher with a bookkeeping function of carbon removals and their distribution inside the vegetation system. At the interface point to {PROD} we divide the harvested plants into five flows. The raw materials for cereals and feed, the raw materials for fats and oils, the raw materials for fruits, the vegetables and the raw materials for sugar and products. This was necessary to facilitate a correct allocation of raw materials in the {PROD} module and to harmonize data from different statistical sources - agricultural harvest statistics with foreign trade and industry/trade production statistics used by {PROD}.

The analogue dispatcher *A_harvest animals* serves for the bookkeeping of the carbon within and out from husbandry. The harvest from living animals (e.g. milk, eggs) and the harvest from dead animals (e.g. meat) is sent to {PROD} in separate flows.

As they are directly linked to other modules like {ENERGY} and {PROD}, these two dispatchers show high relevance for the total carbon modeling system and allow a control of model consistency.

Husbandry

Husbandry is subdivided into cattle, pigs, poultry and others. The partitioning between these types of animals was made because each type has its own manure management and the relative importance of stock size to annual meat production is different. A development that changes only the contribution of one animal species to the living carbon pool, not the total carbon amount, could anyhow cause a different carbon release from the produced manure into the atmosphere as a consequence of differences in manure management. The C-CH_4 production per head and year from the enteric fermentation of cattle is more than fifty times higher as the production from swine. This example shows, that it is necessary to distinguish between the different animal species especially for scenario assumptions (s. also under A 2-2.4)

These two main parts of living biomass are in permanent interaction with other compartments like the soil or the atmosphere. The module is connected with the other modules either through interface flows, for example the flow *AP_harvest* from plants to the module {PROD} or with information flows about the demand, for example the demand of energy for agriculture *(AE_ energy demand for agriculture)* see also Figure A1-1. This information flow causes a carbon flow in one of the other modules, in the example given inside the module {ENERGY}.

Soil

Soils, like in many other ecological contexts act as an important sink. A huge amount, namely about 55 MtC in agricultural and 190 MtC in meadow soils *(Dersch & Böhm 1997)* are stored within Austria's agricultural topsoils. A linear first order estimation indicates that 1990 carbon losses from soil humus due to arable land-use practices and organic matter decomposition are possibly more than twice as large as carbon emissions from domestic livestock *(Jonas 1997*). Many authors *(e.g. Schlesinger 1999*) stress the potential storage capacity of cultivated soils for the reduction of carbon dioxide emission to the atmosphere. Consequently special attention is paid to the precise estimation of soil carbon stocks, the modeling of soil carbon turnover and to the description of carbon sequestration or release in and from soil, respectively.

A compartment modeling approach as shown in Figure A1-3 was chosen by exploration of the SOMNET database *(Smith et al. 1997, 1999*). The used three-compartment soil model is based on well established concepts (Jenkinson and Rainer 1977; Paustian et al. 1992; Parton and Rasmussen 1994; Van Dam et al. 1997) and adapted to the data availability for Austrian soils.

This agricultural soil model is coherent to that one used in the module {FOREST}, allowing the representation of land-use changes without difficulties. Consequently different litter qualities (e.g. “wooden litter”) can be considered in the modeling concept. In forest soils resistant plant inputs lead to the accumulation of a discrete litter layer covering the mineral forest soil compartment below, while in {AGRO} a considerable part of input plant residues is quite labile and decomposes to CO_2 in the respective year of its arrival at the soil surface (“labile litter”).

An important change in the carbon pools is expected to be due to land use change between the module {FOREST} and {AGRO}. These changes occur in both directions but with different implications for carbon storage *(Oberländer 1992)*. Nevertheless, both legal restrictions and statistical data of the last decade point out the main direction of land-use change leading to an extension of forest land on former agricultural land due to afforestation and natural tree growth on abandoned meadows. Because of the parallel soil model for {FOREST} and {AGRO} modules it is possible to simulate this development and its effect (sequestration or release of carbon) on the carbon balance.

The hydrosphere is not represented as a separate module (like the atmosphere). It was decided to consider the hydrosphere as a pool in {AGRO} receiving inflows from all other modules. This decision was made because a first estimation resulted in marginal carbon fluxes (< 0.1 MtC/yr) from/into the hydrosphere.

A 2-2 Methodology

A 2-2.1 Data availability

A 2-2.1.1 Agricultural production data

Data availability and relevant literature sources of the ACBM agricultural database are listed in Table A 2-1. Recently the "Electronic data handbook" was made available for public access by the Austrian Institute for Agro-Economics *(Handschur 1998; AWI 2000).* This compilation includes the annual statistical data (starting in 1981) of Austria’s agricultural production (both meat and vegetation) and the figures of living animal stocks and import/export relevant quantities of Austria's agriculture. Additionally figures of the farmers economic status, land use changes and financial support payments are listed on an annual basis.

Necessary input data, not available from official statistics were derived from primary data, or – if impossible – estimations based on literature values were used for the implementation within the ACBM model.

Table A 2-1: Data availability and integration in the {AGRO} module

EDH: electronic data handbook *(Handschur et al. 1998*) based on reports of the Central Bureau of Statistics
OK: data available and implemented
DERIVED: data not available but derived from other data sources

Type of data	Data source	Status of integration
Annual plant harvest	EDH	OK
Annual grassland harvest	EDH	OK
Annual plant production from other land-use (wind-protection belts etc.)	Estimated *(Körner et al. 1993; Erb 1999)*	OK
Annual soil inputs from plant production	DERIVED (from harvest data)	OK
Annual C-input to hydrosphere	DERIVED *(Maringer & Ramer 1998; WWK/UBA 1998)*	(marginal)
Biomass for heating purposes	{ENERGY}	OK
Import/Export of agricultural products	EDH, {PRODUCTION}	see {PRODUCTION}
Annual production of living animals	EDH	OK
Living animals	EDH	OK
Annual production of meat and by-products	EDH	OK
Annual import/export of living animals	EDH	OK
Annual C-output due to fermentation of manure and respiration of living animals	DERIVED *(IPCC 1996)*	OK
Annual biogas production	Estimated *(Amon, 1998)*	OK
Annual soil inputs from animal manure	DERIVED *(IPCC 1996)*	OK
Annual production of compost from house-garden wastes	Estimated *(Amlinger 1993)*	OK
NPP grassland	Estimated (based on harvest data from EDH; *Ellenberg 1996; Haberl 1995*)	OK
NPP croplands	DERIVED (sum of harvested biomass + residues)	
Annual energy demand for agricultural production	DERIVED, {ENERGY}	OK
Soil carbon	BORIS *(FEA 1999)*	OK
Daily Feed demand of animals	ESTIMATED *(Kirchgessner 1997; NRC 1994, 1998)*	OK

For the conversion of harvest data to dry matter of plant material and finally to harvested carbon and byproducts, respectively, expansion and conversion factors, as listed in Table A2-2, were used.

Table A 2-2: Conversion factors from fresh harvest material to dry matter and carbon content (from *Schidler 1998*, partly adapted: [a]: *KARLSON 1988*)

cereals	fresh to dry matter	fraction of carbon in dry matter	ratio harvest product to harvest residues/by-product (dry matter basis; C-content of residue = 45%)	
wheat	0.86	0.45	0.817	straw : seed
rye	0.86	0.45	1.29	straw : seed
barley	0.86	0.45	0.903	straw : seed
oats	0.86	0.45	1.032	straw : seed
maize	0.85	0.45	1.105	straw : seed
crops				
potato	0.22	0.42	0.088	leaves : tuber
legume seeds (pea beans)	0.86	0.45	0	feed
clover hey	0.87	0.45	0	feed
silo-maize	0.22	0.45	0	feed
sugar beet	0.23	0.40	0.184	leaves : beet
feed beet	0.13	0.40	0	feed
sunflower (plant)	0.15	0.45	0	feed
green rape (feeding)	0.15	0.45	0	feed
oil seeds				
sunflower (seeds)	0.91	0.73[a]	3.731	straw : seed
rape	0.91	0.73[a]	1.729	straw : seed
oil pumpkin	0.91	0.73[a]	75	pulp : seed
vegetables/fruit				
cabbage, pepper, onion	0.12	0.45	0.1	residue left on field
lattuce, spinach	0.08	0.45	0.1	“
carrots	0.16	0.45	0.1	“
red beet, peas, beans	0.22	0.45	0.1	“
tomato, cucumber	0.06	0.45	0.1	“
walnuts	0.86	0.45		
apples/pears	0.22	0.40		
other fruit from trees	0.2	0.40		
wine	0.02	0.40		
animal products				
meat	0.30	0.54		
eggs	0.26	0.59		
milk	0.13	0.53		

Table A 2-3: Conversion factors from living animals to slaughter weight

cattle	0.57	*Bittermann & Paller 1999*
pigs	0.75	*Frickh et al. 1998; Lettner et al. 1998*
poultry	0.78	*Leitgeb et al. 1998*

Table A 2-4: Assumed body weight and daily intake of living animal *stocks (from Kirchgessner 1997; Nat. Council of Nutrition.1994, 1998)*

Animal category	daily intake (kg dry matter / d)
juvenile cattle < 2 a	7
bulls/oxen/cattle fat stock > 2 a	16
milk cows	16
foals < 1 a	7
young horses 1-3 a	13
adult horses 3 a and older	11
piglets to 20 kg	0.8
young pigs 20-50 kg	1.8
pig fat stock >50 kg	2.4
breeding sows > 50 kg	3
boar > 50 kg	2.9
sheep	1.5
goats	1.2
chicks and young chicken < 0.5a	0.06
laying hens	0.12
cocks	0.12
broiler chicken	8 kg in lifetime (< 1 a)
goose	0.20
ducks	0.18
turkey	0.29

Soil carbon data

In 1994 the Austrian Federal Environment Agency (UBA) has started a project aimed to the development of a data key for the harmonized soil data registration in Austria. Existing soil data have been collected for different purposes. Consequently, these soil data are based on different sampling methods adapted to the studied issues, spatial scopes of the respective investigations, and different methods of analysis. This, together with different electronic data processing formats render a comprehensive data interpretation all over Austria difficult *(Schwarz et al. 1999*). Since several years at FEA a database named BORIS was developed for unification and integration of existing Austrian soil analyses data. It is available for application since March 1999. At the moment BORIS contains already more than 300.000 single entries of more than 5000 locations in Austria *(FEA 1999*), including soil survey data of Burgenland, Upper Austria, Styria, and the Tyrol. As investigations carried out in the framework of the

Austrian Soil Survey ("*Bodenzustandsinventur*", BZI) are conducted by Austria's federal country administrations, the resulting soil data are managed by the respective regional administrative bodies, and permission for the usage of the existing data sets has to be gained from each federal country contributing to the database before a data query and retrieval from the joint data bank is possible.

To derive carbon stocks of agricultural soils from the available soil data, which report carbon as % weight or % humus (weight) in fine soil (< 2 mm sieved), some assumptions and calculations were made:

- **soil density:** data were available from Soil Survey Upper Austria. For all other cropland soil data the relation reported by *Körschens & Waldschmidt (1995)* was used, where soil density is defined to be 1.5 g cm^{-3}, reduced by 0.007 g cm^{-3} per each 0.1 % C_{org}. (e.g. a soil with 2.2 % C_{org} would have a soil density of 1.5 – 0.007 * 22 = 1.346). The equation gave good agreement with the Upper Austrian cropland soil density values (± 10%), and thus was applied for derivation in all other cases.
  For grassland soils in the Upper Austrian Soil Survey a graphic regression was reported between soil density and organic matter content of surface soils *(BZI OÖ 1993)*. This relation was generally applied for grassland soils of other federal countries.

- **skeleton content:** measured data were not available, and therefore had to be derived from literature values *(e.g. Gerzabek et al. 1991)*. Quantification of the skeleton content is necessary for carbon stock derivation, because soil density normally is reported for undisturbed soil, while organic matter analysis is performed with sieved (< 2 mm) soil samples. Therefore, if skeleton (i.e. gravel and coarse sand), which consists of solid minerals without any organic matter, is neglected, carbon stock would be significantly overestimated.

The chosen assumptions are listed in Table A 2-5. As extensive grasslands often are located in mountainous areas with shallow soils, an average soil depth of only 40 cm is considered.

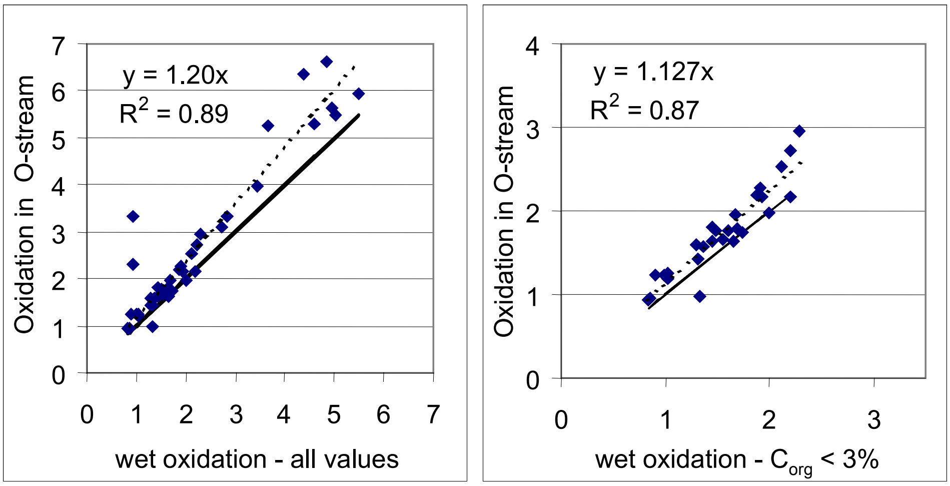
Table A 2-5: Fraction of skeleton content (% weight of sand/gravel > 2 mm) in different agricultural soils and soil depths

	cropland soil	int. grassland soil	ext. grassland soil *
0-20 cm	0 %	10 %	20 %
20-50 cm (20-40 cm*)	20 %	30%	40%

- **carbon content:** from the BORIS database values are available for Burgenland, Upper Austria, Styria and for the Tyrol. For Lower Austria and Salzburg published data from printed reports were used. If necessary, humus content was recalculated to organic C content by multiplication with 1.724 *(according to Blum 1996)*. For Vienna C-values of Lower Austria, for Carynthia values from Styria and for Vorarlberg C-values of the Tyrol were used.

- **Methods of carbon determination**: There are several methods available for the determination of organic carbon in soil samples. Wet oxidation with dichromate solution *(ÖNORM L1081)* in soils containing more than 5% humus tends to yield systematically too low values, because of incomplete disintegration of organic compounds. This is especially problematic in the analysis of forest soils, but also for grassland soils the total oxidation in O-atmosphere is highly recommended *(ÖNORM L1080) (Mutsch, personal communication).* An improvement of the wet oxidation method can be achieved by external heat application during the analysis.Derived from an intercomparison study *(Mutsch 1994)* and some additional soil enquete data (ALVA 1998, 1997, 1996), a relation was set up, to correct wet oxidation carbon data. The resulting relation is given in Figure A 2-1. According to this relation the following correction factors were applied to wet oxidation carbon data: up to 3% C_{org}: 1.13; 3-7% C_{org}: 1.2; 7-8.99% C_{org}: 1.24; 9-11.9% C_{org}: 1.3; 12-14.9% C_{org}: 1.35; 15% and more C_{org}: 1.4

Figure A 2-1: Relation between wet oxidation *(ÖNORM 1081)* and total *oxidation (ÖNORM 1080)* carbon data in soil samples *(Data from ALVA 1998, 1997, 1996, Mutsch 1994)*



- **Statistics:** A data analysis showed, that most classes of carbon data follow a log-normal distribution. Therefore, geometric means and geometric standard deviations were calculated for data description and carbon stock estimation.
- **temporal trends**: Sampling for the soil surveys from the respective federal countries covered several years and the reference date for most data is around 1990. In the Tyrol a repeated sampling was performed in 1996 *(BZI Tirol 1996).* Unfortunately the carbon analysis method was changed between the two survey dates, therefore a comparison is very difficult and results could not be considered for ACBM. In absence of other information's it had to be defined *(in accordance with Dersch & Böhm 1997a)* that carbon content as determined in the 1990ies are in equilibrium after carbon losses due to intensification of agriculture during 1960 - 1980.
- **regional integration**: for the estimation of representative mean values, the results of land use classes of federal countries were weighted according to their proportionate area within the total area of the respective land-use class. Regional differentiation of land uses are very pronounced, e.g. 77% of extensive grasslands are located on the area of Tyrol, Vorarlberg, Salzburg and Carinthia, while 82% of croplands are present within Lower Austria, Burgenland and Upper Austria.

The results of the described calculation procedure are listed in Table A 2-6 for different land-use classes. Average carbon contents in cropland and vineyard soils are destinctly lower than values for grassland or housegardens. Under extensive grassland soil carbon storage is considerable.

Table A 2-6: Derived average soil carbon stocks (tons C per ha) in Austrian agricultural soils (weighted averages of federal country results)

landuse category on agricultural areas of Austria	0-20 cm depth $t\ C\ ha^{-1}$	20-50 cm depth $t\ C\ ha^{-1}$
cropland	41.33	18.24
intensive used grassland	60.47	20.52
extensive used grassland	91.82	27.19
vineyards	39.31	18.26
orchards	56.92	16.77
house gardens	57.77	25.25
tree nursery	93.02	19.91
abandoned grassland	68.90	29.80

A 2-2.2 Data and knowledge gaps

Regionalisation and the influence of management practice met considerable problems, due to the lack of a spatially explicit modelling approach. In the case of the question, how crop rotation can influence the carbon storage in soils, this lack prohibits a consideration. For management practice it turned out, that only few specific data relevant for Austria are available in published form.

The representation of organic farming within ACBM is not possible in full detail at the current (necessary) level of aggregation. So it was decided to *focus (in accordance with Freyer 2000, personal communication)* on less complex management modifications, namely ÖPUL-actions (extensivation), where it was assumed, that harvest decline is very moderate *(in accordance to Pirringer 1997; Kirner & Schneeberger 1999)*: up to 15% on croplands and 15% on grassland and housegardens compared with the traditionally cultivated areas in Austria.

It should be mentioned that the benefit of organic farming for reducing greenhouse gas emissions to a large extent is due to a reduction of nitrogen-containing emissions (which are not taken into account in ACBM) and the reduction of fossil fuel based emissions (herbicides, tractor fuel, energy demand for mineral fertilizers).

A 2-2.3 Model design

Different problems need different modeling approaches. The objective or purpose of each study will determine whether a largely empirical or statistical model will suffice, or whether a more mechanistic model is needed. Resource implications (time, staff and funds) will impinge on the final decision; at the same time it is essential that an adequate level of scientific rigor is maintained. Our aim was to build a model that could help policy makers within their decisions. To fulfill this demand we have developed our module from two different viewing points. Policy makers want to know how a decision would influence official statistical data because these are the data they have to report to international organizations. Within a Bottom up approach we used official national data to determine carbon fluxes in Austria. As it is not possible to understand the complex structure of the carbon cycle only from census data we combined the Bottom up with a Top down approach. The Top down approach looks at the overall structure of the carbon cycle. Through this combination we developed a modular carbon system, which is based on official data, thus the results for the years 2000 to 2010 from the simulation can be compared with the collected data for these years in the future.

Hence it is possible to retune the module with data collected in the following years which represents an essential benefit of such a data based module. Some data of the model is very uncertain e.g. methane emissions per capita caused by cattle, or how much feed a cow needs per year. Biological systems in particular due to natural fluctuations show a high level of variability. In such cases a retrospective retuning of the ACBM model (with newly available census data e.g. for the year 2000) will help to improve the accuracy of model predictions in the future.

The model structure is illustrated in Figure A2-2. While the two sub-modules of Vegetation and Husbandry are driven by statistical data and outputs mainly are derived by expansion factors (see Tables A2-1 and A2-2), the modeling of the soil compartment and linked outputs due to a lack of measured informations was based on a more process-oriented approach.

As many of the models presented in SOMNET need input data on a monthly or even daily time scale to provide the representation of seasonal variations in C and N dynamics in soils, only a minor number of models turned out to be suitable for our context of annual time steps. The four compartments included in the current ACBM soil model (see Figure A 2-3: 3 soil compartments plus organic inputs to the soil surface) are seen as a minimum to facilitate all functionalities needed for soil carbon dynamics estimations and the modifications of these processes by changing agricultural practice and addition of organic amendments.

Accordingly, to minimize parameters, no differentiation of organic matter decomposition between soil horizons/soil depth is taken into account. For agricultural soils most inventory data are available for the plough layer (0-20 cm depth), in grassland soils the reference depth is fixed to 0-20 cm, too, although most data refer to the main rooting depth of meadow vegetation only (0-10 cm). The huge carbon pool situated below these depths is estimated to a depth of 50 cm but not subjected to dynamic soil modeling.

Figure A 2-2: {AGRO} model structure

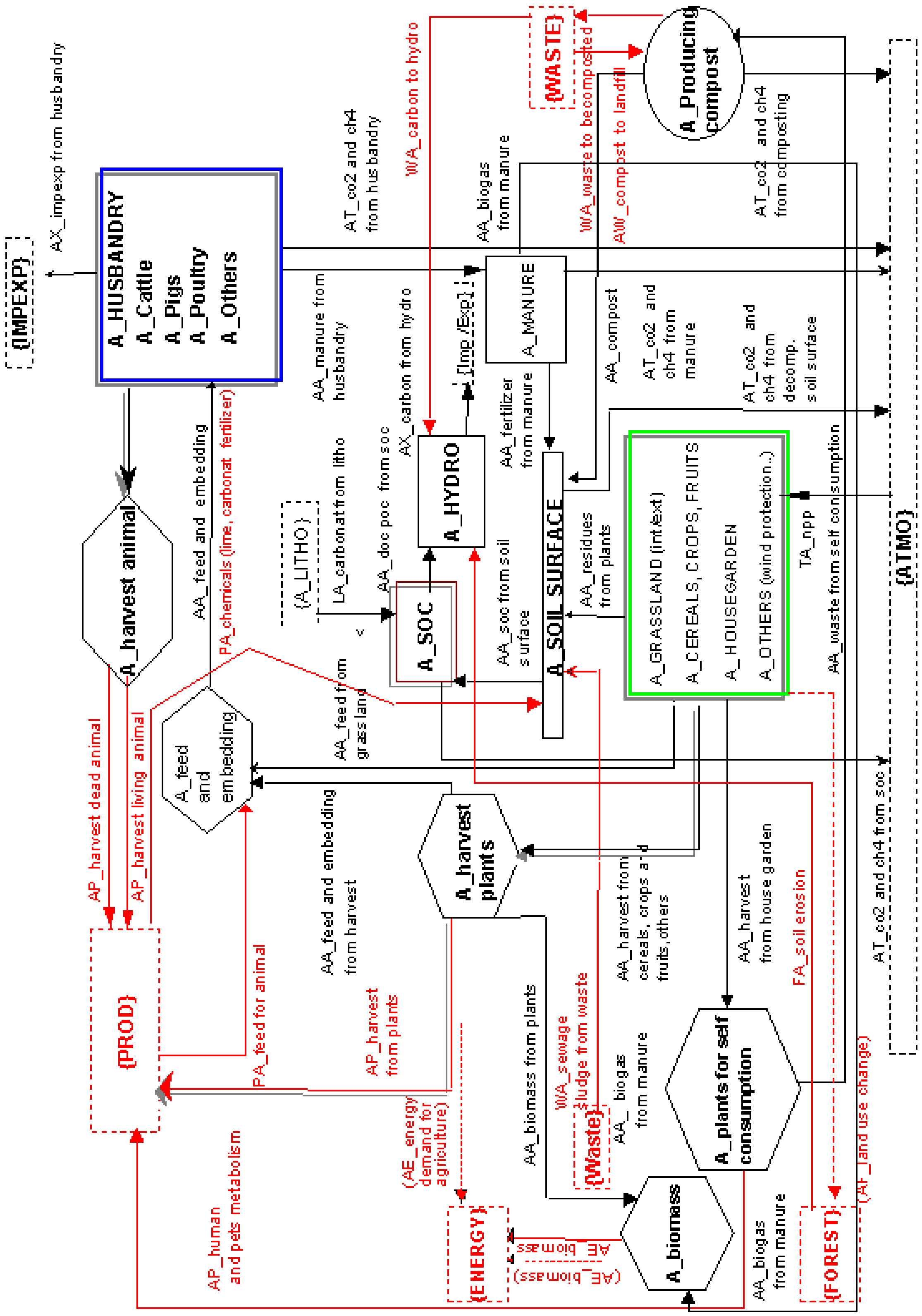
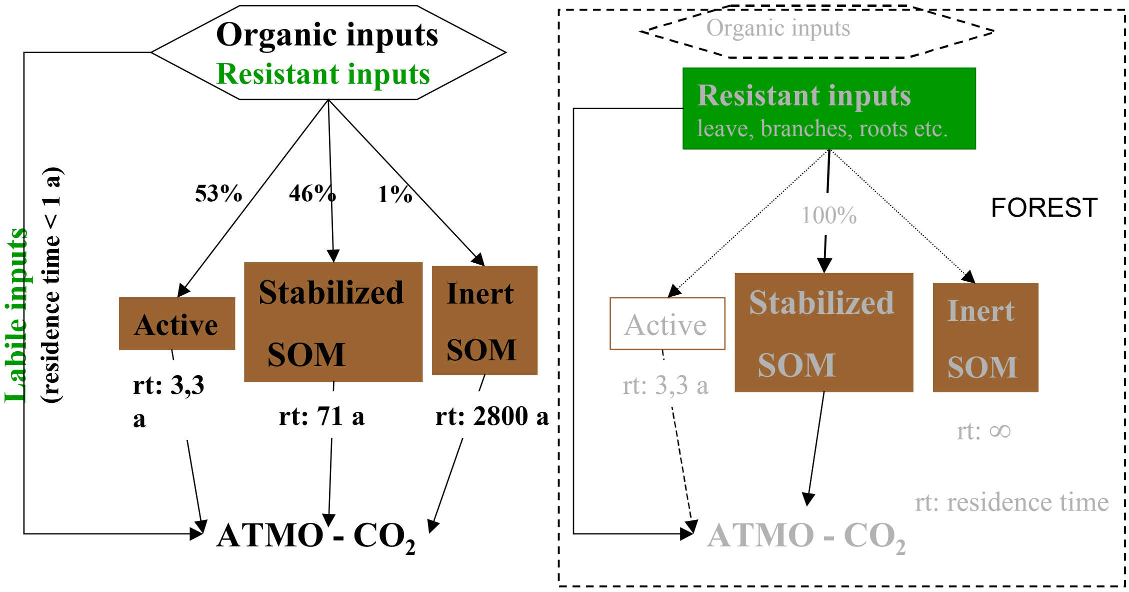


Figure A 2-3: Soil sub-model within module {AGRO} and {FOREST}



Carbon inputs into agricultural soils are considered separately according to their organic matter quality determining the fraction of “labile organic inputs” with a residence time of less than one year (represented as a direct CO_2 emission to the atmosphere). Resistant organic soil inputs are distributed to the three considered Soil Organic Matter (SOM) pools: the "active" SOM pool represents microbial biomass and readily decomposable products with fast turnover leading to residence times of a few years. Resistant plant residues or physically protected organic matter remains in the "stabilized" SOM pool. Residence times in this compartment typically last for decades. The "inert" SOM pool contains material chemically and physically protected against decomposition, here residence times are extended over centuries and therefore, in the time period considered in the current context, changes within this pool can be neglected. Nevertheless this pool contains a huge amount of carbon.

As pointed out above, ACBM is based on statistical data. These data are extracted from different sources and therefore have to be checked for consistency and, if necessary, have to be balanced and unified. In a co-operation with IIASA/Laxenburg this evaluation is carried out to create a coherent data basis for the whole model and the different modules, respectively.

Another great problem is how a change of one parameter influences all the others? In a statistical model such as the ACBM a direct influence cannot be insinuated easily. For this reason coefficients were used that determine the outflow of a pool in dependence of the pool size itself. Consequently, a time delay between the pool and the corresponding flow within the respective time step, corresponding to one year, exists. It is assumed that a given carbon flow (in- and outflow) for example from 1990 determines the pool size of 1991. As in agricultural production the harvest takes place within a few days at the end of the growing season, and therefore the assumption of a single time event seems to be an acceptable simplification.

A 2-2.4 Scenarios

Quantification of current trends was based on literature values were available:

In the “No Major Change” scenario (NMC) we tried to derive current trends from the years 1990 to 1998 and project them unmodified till 2010.

In the “Towards Sustainability” scenario (TS) more or less realistic (i.e. mostly small) modifications of NMC trends were defined into direction of a more sustainable development to avoid unacceptable influences on economic and social systems, which cannot be assessed within the framework of ACBM. The increase of the number of vegetarians in Austria seems relatively high (see Table A 2-7). Nevertheless, in the years 1990 to 1998 a considerable decrease of the beef consume was observed in reaction to the “BSE Scandal. Moreover an analysis of age structure in food preferences *(Elmadfa & Burger 1998*) shows that 6% within the group of young people (< 20 years old) stated to live vegetarian as compared to the group of adult Austrians, from whom only 2 % consume a meat-less diet. . Under the assumption that half of today’s youth will keep their nutrition habits at adult age, an increase of vegetarian consumers can be expected.

The current land use change *(Brandstetter & Wenzel 1997)* and the assumption of the land use change for the years 2000 to 2010 was chosen in accordance with M. Jonas (2000 personal communication).

Assumptions for the realization of extensivation in agriculture were based on investigations carried out by the Federal Institute of Agriculture Economics and other qualitative statistical reports (*Kirner & Schneeberger 1999*; for the two scenarios have been made because of the results in other studies *(Pirringer 1997a).*

The use of new energy sources, in particular a trend of increased biomass use for energy production was quantified on the basis of expert projections (see also Annex A-3).

The basic assumptions for scenario definitions and quantification of driving parameters in {AGRO} are summarized in Table A 2-7.

For the module {AGRO} economic development is expressed by alterations in land use demand, life style trends lead to a shift of nutrition patterns towards less meat consume. Technical achievements are realized in an improved and increased use of biogenic energy sources (e.g. space heating). Moreover changes due to legislation measures (municipal waste dump legislation, agreements for the fulfillment of Kyoto-Protocol) are taken into account.

Table A 2-7: Relevant driving bags and their translation to specific driving forces influencing the future development of agriculture according to the two scenarios

	NO MAJOR CHANGES (REFERENCE) (2000-2010)	**TOWARDS SUSTAINABILITY (2000-2010)**
DB ECONOMIC DEVELOPMENT	*Economic development will be around growth rates of 2,5 % GNP p.a.* *Contribution of agriculture to GNP will slightly decrease. Growth rates will mainly come from services and leisure tourism. Production will shift from primary to secondary products.*	*Economic development will be around growth rates of 2% GNP p.a.* *Contribution of agriculture to GNP will remain the same. Growth rates will mainly come from services and leisure tourism. Production will shift from primary to secondary products, with more products from renewable raw materials.*
DF Land use demand	Continue of present land use change from AGRO to FOREST (6000 ha/yr)	Increase of land use change by 4% p.a.(i.e. 6240 ha in 2001)
DB ECONOMIC STRUCTURAL CHANGES	*Economy will shift from primary to tertiary sector. Increase of IT-based economy. Consumption of goods will increase. In energy sector shift from coal/oil to gas.* *2 % increase per year of the area for extensive agriculture. Agricultural output remains the same. Cheaper world prices for electricity & increased imports of primary products, food, and feed.*	*Economy will shift from primary to tertiary sector. Increase of IT-based economy. Consumption of goods will increase. In energy sector shift from coal/oil to gas. Slowly increasing use of renewable energy sources. 4 % increase per year of the area for extensive agriculture. Agricultural output has an slight decrease due to the extensivation of agriculture.*
DF Agricultural development	Increase of extensive Agriculture 3 % p.a.	Increase of extensive Agriculture 5 % p.a.
DB LIFESTYLE	*Continuation of 1990-2000 rates of single households, environmental awareness, nutrition patterns, vehicle mileage's.* *Increasing vehicle use for „fun" matches decreasing commuting because of teleworking.*	*Continuation of 1990-2000 trends, but less vehicle use (decrease in annual vehicle mileage by 5 % until 2010), more environmental awareness, more vegetarians.* *Increase of natural forests and changes of forest management strategies*
DF Nutrition patterns	Continuation of current trends in meat consume	Decrease in meat consume under current trends.
DB POLICY	*80 % efficiency of municipal solid waste dump regulation; Kyoto goals not met*	*100 % efficiency of municipal solid waste dump regulation, achievement of Kyoto goals.*
DF Kyoto protocol: C-sink establishment	Increase of present land use change from AGRO to FOREST (6000 ha/yr) by 1% p.a.	Increase of land use change to 2% p.a. (in addition to DF land use demand).
DB TECHNICAL DEVELOPMENT	*Continuation of current trends*	*Increased efficiencies above current trends*
DF New energy sources (=biomass)	Continuation of current trends (Increase by 2% p.a.)	Increase of 2 % above current trends for heating materials and 4 % for biogas

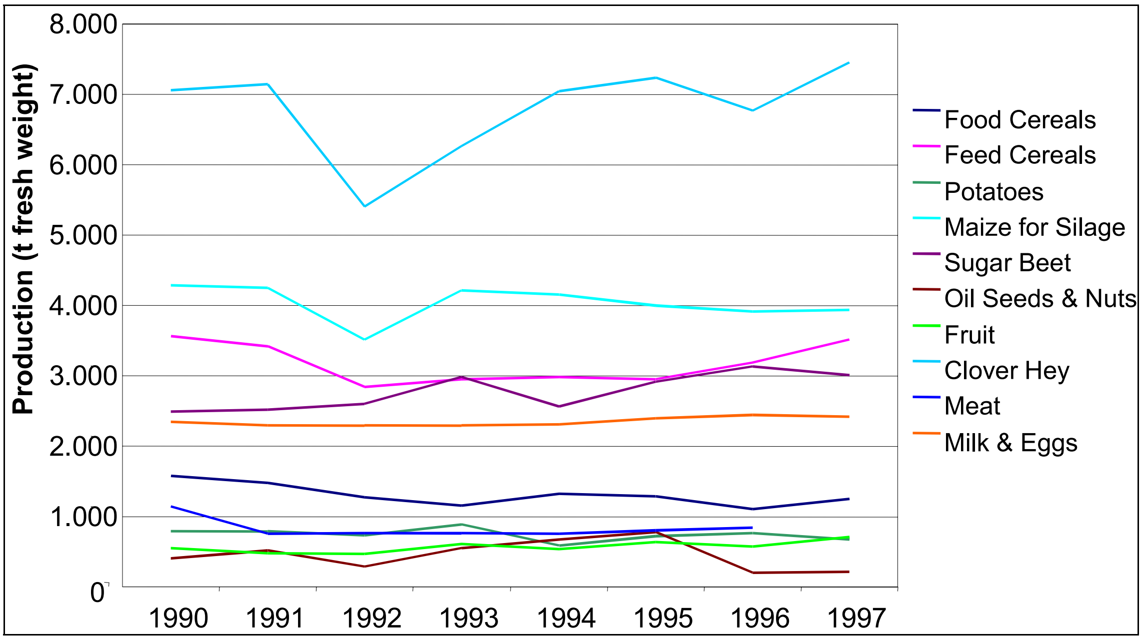
A 2-2.5 Model Formulation

Model

For the implementation of our model we decided to use EXCEL and Visual Basic. In the first step we have started the modeling for several parts of the model like HUSBANDRY or VEGETATION and simulated these parts separately. In this simulation the parameters were chosen in a way, to leave the pools (levels) of the model stay in an equilibrium state. In the next step of model-construction existing parts of the model were interconnected. After the connection of the steady state sub-models the resulting connected model was checked to remain in a steady state condition as well. Due to this model building procedure the model structure and behavior remained controllable at every step and system inherent errors were detected easily. Our model is a discrete model with a simulation time step of one year in general (with few exceptions e.g. inside the soil system, because of the partly faster decomposition-rates of labile material).

As mentioned above besides transparency considerations the model structure was chosen according to data availability. In particular statistical data from 1990 to 1997 are used to derive a transfer rate for each flow. These rate coefficients determine the outflow in relation to the pool level itself. For the years 1998 to 2010 or further these rates are used to estimate the flows. To find realistic rate coefficients is therefore a crucial point of the whole model development. It had to be decided for each flow whether calculation of a mean value of the years 1990 to 1997 or regression functions were used as most appropriate derivation methods. Figure A 2-4 shows that agricultural production of crops and animal products have a considerable variation over the past years and only some products show consistent trends.

Figure A 2-4: Time dependent fluctuations of Austria's annual agricultural production



In the year 1992 agricultural production was significantly lower than in average years because of bad weather conditions during the growing season. Here it should be said that our model does not deal with climatic changes, but annual weather events are implicitly accounted for by not correcting extraordinary yearly data. We took the values of the production over the time period 1990-1997. From annual harvest values coefficients for the production as a function of the cultivated area (t per ha) were calculated as arithmetic means. As illustrated in Figure A 2-4 in most harvest products mean values across the whole observation period turned out to be an appropriate descriptor of temporal development. These coefficients were used to simulate the production for the years from 2000 to 2010 or 2020.

Although model validation cannot be performed with the existing data set (because this data set was used for parameter derivation), a test of consistency and correctness in model structure can be performed, using the derived rate coefficients to simulate the carbon status for the years 1990 to 1997, the period with measured data available. In the case of errors in the modeling structure, detectable deviations of modeled values from measured data are expected to occur. Only after this test of constancy the linking of ACBM modules was carried out stepwise with further checks of consistency. Finally, prior to interconnecting the ACBM modules together, the boundaries of each module and connecting interfaces have been defined and cross-checked (see example from interface list in Table A2-8) to assure that transboundary carbon flows are corresponding. In this way disturbances of established intra-module balances can be avoided and all flows are traced from origin to destination minimizing the danger of unintentional losses from the overall carbon balance. Because all these precautions have been met, a robust carbon model was achieved assuring a consolidated modeling base for scenario calculations.

Table A 2-8: Detail from the interface list: {AGRO} related trans-module flows (atmosphere excluded)

Destination	Name of Flow or Pool	Unit	Comments	1990
E_domestic	(AE_energy demand for agriculture)	PJ/yr		24.00
E_biomass	(AE_biomass)	PJ/yr	energy from agricultural biomass	4.34
E_biomass	AE_biomass	MtC/yr	biomass for energy production	0.12
{FOREST}	(AF_land use change: Area)	ha/yr		6000
{FOREST}	(AF_land use change: C_Content)	MtC/yr	carbon stocks 0-50 cm soil depth	0.40
P_food and feed industry	AP_harvest living animal	MtC/yr	milk	0.17
P_food and feed industry	AP_harvest dead animal	MtC/yr	slaughtered animals (living weight)	0.18
P_food and feed	AP_raw materials fats and oils	MtC/yr		0.120
P_food and feed	AP_raw materials cereals and feed	MtC/yr		2.22
P_food and feed	AP_raw materials fruits and vegetables	MtC/yr		0.07
P_food and feed	AP_raw materials sugar and products	MtC/yr		0.23
P_CONSUMPTION	AP_human and pets metabolism	MtC/yr		0.03
A_husbandry	PA_feed for animal	MtC/yr		1.14

It has to be pointed out that predicting the future is only possible with a certain probability. To estimate the uncertainty of our predictions we have to take into account uncertainties within the collected data sets. It would be very though to find the uncertainty from all data involved, therefore, in the first step sensitivity analyses were carried out within each module to identify parameters with great influence on module behavior. For these selected parameters we have quantified data uncertainties. Finally with these uncertainties the uncertainty of our modeling results was calculated by use of the EXCEL software extension @Risk, which is designed for such purposes.

Both scenarios (No Major Changes, Towards Sustainability) have been analyzed. The cornerstones of the two scenarios are discussed in chapter (A2-2.4). For both scenarios driving force parameters have been defined and their influence on the whole model was investigated. A limited number of important driving forces for {AGRO} was identified and by sensitivity analysis their relative impact on modeling output results was calculated. By this restrictive procedure taking into account only important “key” parameters, it was possible to control the extent of system output changes if individual model parameters were modified.

A 2-3 Results

A 2-3.1 Dynamic model behavior

As mentioned above we used official census data in a Bottom up approach.

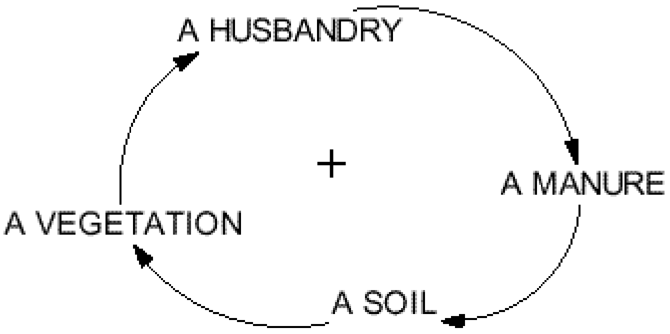
Although if census data is “weak” due to possible shortcomings in precision and consistency, knowing where it is so, i.e. find out uncertainties can make it much more valuable than using any other numbers instead. Fortunately, in Austria annual reporting on agricultural production has a tradition of already 40 years. Moreover the quality of reported values is continuously assessed and improved, where necessary.

Through the two different approaches, Bottom up and Top down, {AGRO} was compiled with a modular architecture at a certain aggregation level, as simple as possible and as detailed as necessary to reach our aim. To understand such a complex model like a national carbon cycle it seems important not to go too deep into detail because otherwise a lot of model assumptions have to be made and error propagation can soon lead to a level of uncertainty which obscures modeling results. Finally the insight into the system behavior would be less than in a ”simpler” model *(Bossel 1994, Bossel 1986)*.

This process of model building can be compared with the difficulty to choose the right simulation time step. With too big timesteps the dynamical behavior could not be shown, but if the time steps are too small then the intrinsic calculation uncertainty could become very large. But there is the momentous difference that normally it is very easy to change the time step, whereas to change the structure of the model needs considerable effort. A modular building approach shrinks this effort.

The module {AGRO} has many feedback loops, for example between the plant production, which supplies the husbandry with feed and the husbandry itself which supplies the soil with manure. If a smaller amount of the plant production is used for feed in husbandry, then there will be less manure, except the missing feed would be imported. This results in less manure spread on the soil and consequently the plant production would be reduced if not the missing plant nutrients would not be compensated by mineral fertilizer application. So there exists a positive feedback in this circle, which is illustrated in the following picture (see Figure A 2-5):

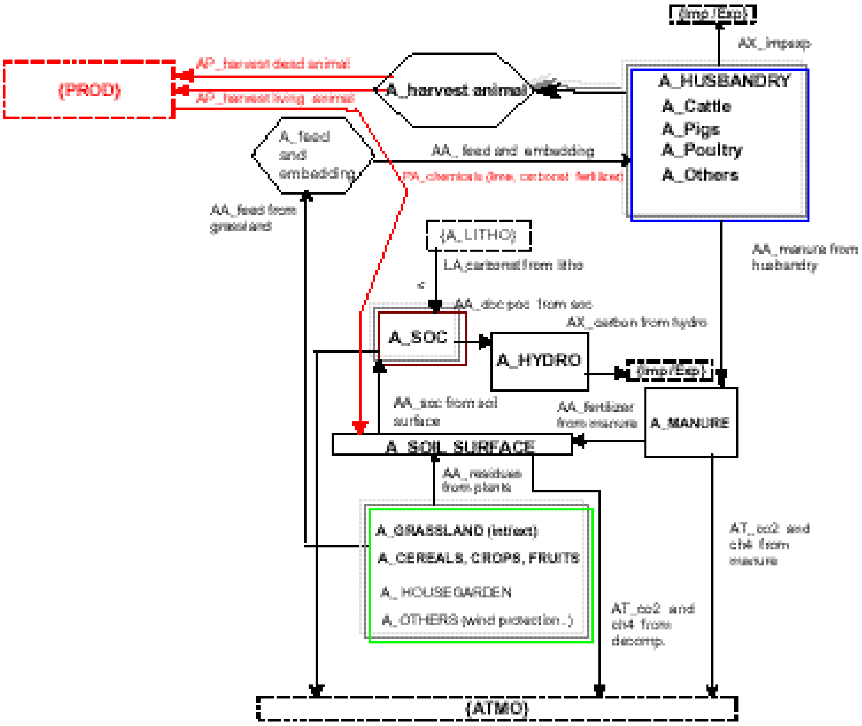
Figure A 2-5: Positive Feedback loop of Plant production and Husbandry



Many such loops can be found in the whole {AGRO} system (see Figure A 2-6 below). Causal loop diagrams (CLD) help to understand the system behavior in a better way and allow to explore the system dynamics within the investigated system. They are also very helpful for developing the model structure: it is often the best way to start with such causal loop diagrams before going into the definition of stocks and flows.

Additional complication of the system can occur because the above shown positive feedback loop facultatively turns into a negative feedback loop if e.g. the manure flow to the soil is very large and therefore negatively influences plant growth conditions. Then further enhancement of the manure flow causes a decrease in the harvested biomass. Many ecological systems are characterized by such a kind of limited carrying capacity which dominates the system dynamics. Therefore, within the {AGRO} Module we only assume moderate changes of the current situation in order to avoid system instability. With the chosen assumptions it is not useful to simulate until 2020 because boundary conditions may not be valid for such a long long time period. Future developments as translated in the formulated scenarios to define boundaries of the agricultural system can be estimated for decades, but then the probability for at present unforeseeable technological developments increases. Another modeling constraint, we have adopted, namely the exclusion of climatic changes due to global change phenomena would become less valid, if the prospection time frame is extended.

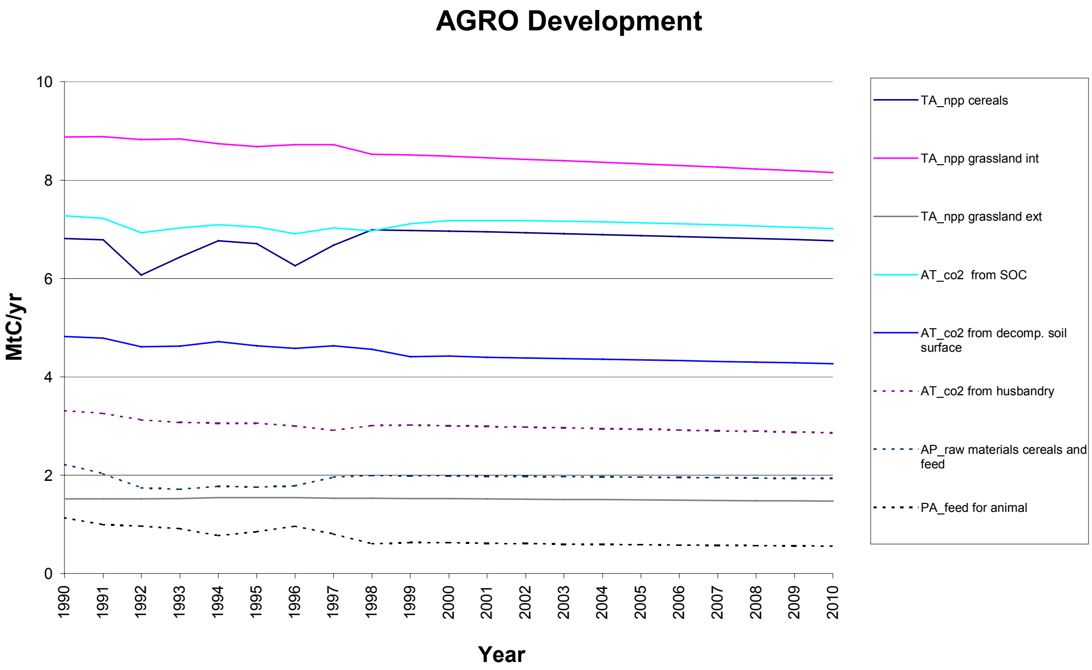
Figure A 2-6: Internal recursive carbon flows in the {AGRO} module:



A 2-3.2 Scenario: No Major Changes (NMC)

In Figure A 2-7 carbon fixation from atmosphere in the phytobiomass of intensive and extensive grasslands and croplands is compared with fluxes to the atmosphere originating from soil carbon decomposition, labile litter decomposition and CO_2 emissions from husbandry: fixation of approximately 17 MtC/yr slightly exceeds emissions of app. 15 MtC. Nevertheless carbon stock in AGRO is not increasing, because part of the produced biomass is directed to other modules (e.g. AP_raw materials; AE_biomass for heating – not shown in Figure A 2-7), and causes CO_2 emissions in the target module.

Figure A 2-7: Fluxes from and to the Atmosphere associated with the {AGRO} module - Scenario "No Major Changes" (NMC)



The temporal development in the NMC Scenario does not show dramatic changes of carbon flows and stocks. Nevertheless in comparison with grassland, cropland NPP shows more pronounced fluctuations for the period 1990-1998, were carbon flows are derived from measured data (see Figure A 2-8).

Figure A 2-8: Annual fluctuation of harvested demands for different cereal crops

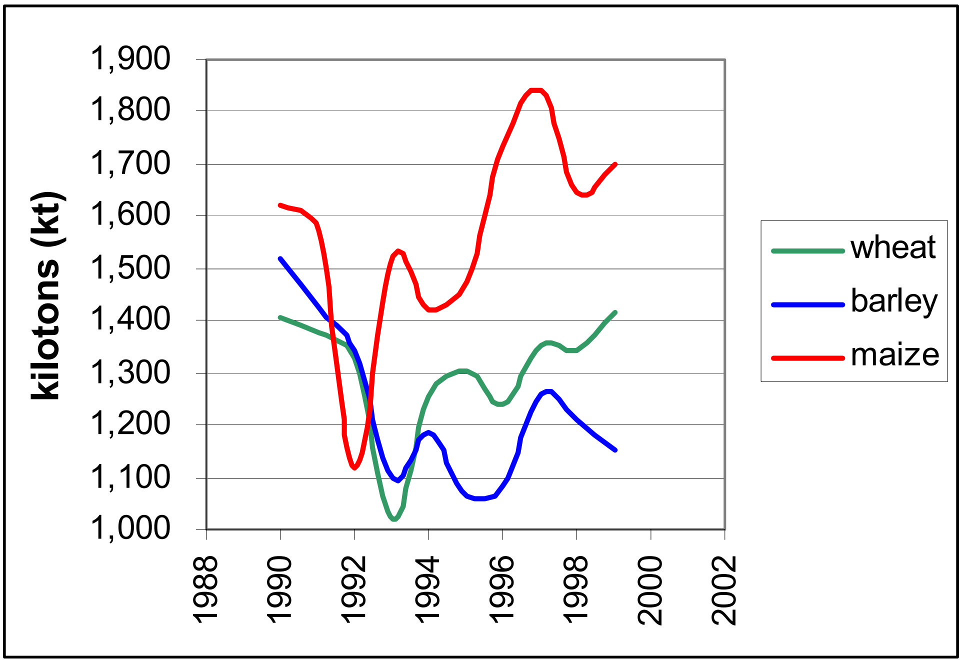


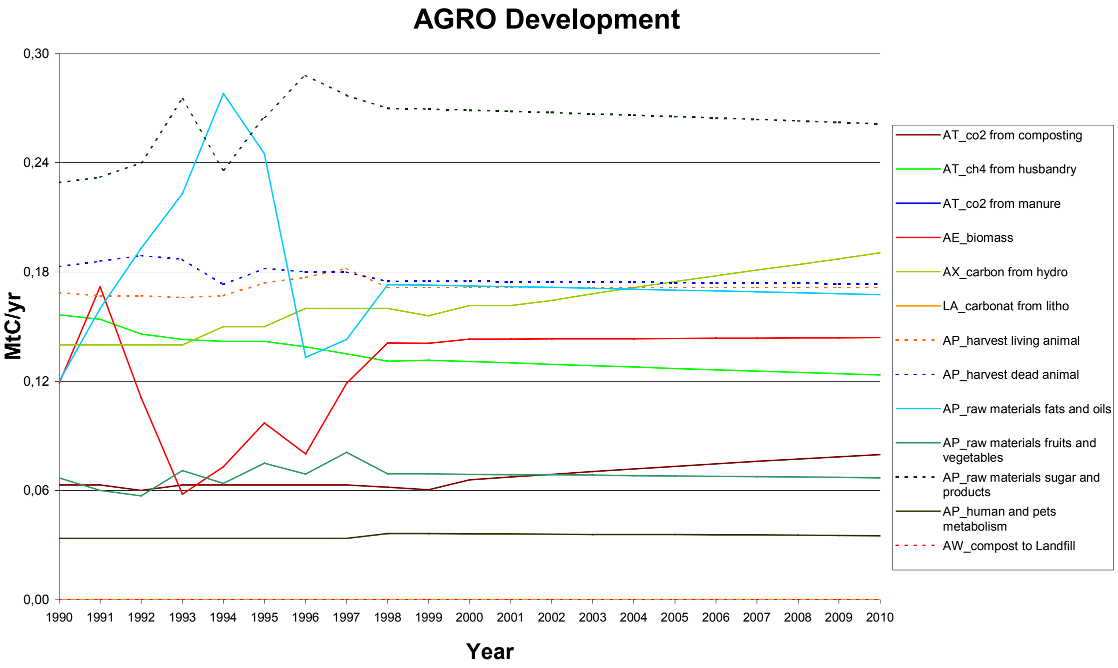
Figure A 2-8 illustrates the large fluctuations of harvested amounts for different cereal crops: while summer drought in 1992 depressed wheat and barley harvests only moderately, maize harvest was severely reduced. In 1993 spring drought influenced wheat and barley production even worse, but for maize production weather conditions were favorable and led to an increase of harvest by 36% in comparison with the previous year. In reaction to poor harvest figures, extended imports of Durum wheat and brewing barley were initiated *(BMLF 1994).* The reduced harvest of 1992 and 1993 to some extent is also reflected in the time course of the flow of raw materials to {PROD} (AP_raw materials cereals/feed).

In the case of grassland such disastrous weather events are less harmful, because harvest date can be postponed and biomass growth is more continuous than in annual field crops.

During the modelled time frame (1990 – 2010) both emissions to the atmosphere and NPP-caused CO_2 fixation slightly decrease. This decrease is caused by land use change between {AGRO} and {FOREST}. In ACBM land use change is realized by a shift of area from donor to target module. If the area of agricultural land is reduced, less biomass is available for NPP within this module. In reality on the respective area, now dedicated to forest production, NPP will stay at the same level or even slowly increase with growing forest trees. So, the decrease of carbon fixation is not a real life phenomenon but only a model calculation item at module level. This artifact disappears if integrated ACBM results (not on module level) are considered, where e.g. NPP of all modules is summed up.

In reaction to economic trends, namely the reduction of profit margins and competition within the European agro-marketplace husbandry continuously decreased in Austria during the last decades. In parallel a slight reduction in the beef consume can be detected from the the available data of the last decade *(Elmadfa & Burger 1998).* This decrease in the living stock of cattle primarily causes a decrease in respiratory CO_2 emissions from husbandry from 3.5 to 3 MtC/yr, and additionally a reduction in the demand of feed from {PROD}, the flow PA_feed for animal (see Figure A 2-7) takes place. As the plant production remains constant, more harvested plants can be used as human food (AP_raw materials cereals/feed) or for the production of biomass and guided to {ENERGY} (see below, Figure A 2-9).

Figure A 2-9: Minor Carbon flows from {AGRO} to other modules in Scenario "No Major Changes"



Minor carbon outflows from {AGRO} are shown in Figure A 2-9. They consist of several disaggregated raw material flows into {PROD} (fats and oils, fruit and vegetables, sugar and sugarproducts) and the harvest of dead (meat) and living animals (milk, eggs). For the interpretation of data fluctuations between 1990 and 1998 the scale of the figure and the absolute smallness of carbon flows should be considered. For oils seeds production *(AP_materials fat and oils)* data variability is intensified by short term changes in the financial support policy for alternative crops before and after Austria's entry into EU. This led to the dramatic peak of harvested amounts in 1994 and 1995, while in 1996 agricultural area cropped with rape and other oilseeds was reduced by app. 30% *(BMLF 1996).* Although high uncertainty of derived modeling coefficients for the calculation of future trends in those small flows is the result of the observed data fluctuations, the validity of the coefficients was assured by a cross-checking of modeling results with the {PROD} module, where future raw material needs e.g. for oil and fats of plant origin are derived independently from production statistics. Both calculations yielded corresponding results.

For the future (1999 to 2010) agricultural production is predicted to remain quite constant. Methane emissions from husbandry show a decreasing trend in accordance with the reduction of cattle stocks as described above.

The flow *AX_carbon into the hydrosphere* (i.e. the sum of carbon emissions of ALL modules, only collected in {AGRO}) has a relative strong increase. This is not caused by {AGRO} itself, but reflects a rise in inputs from the other modules.

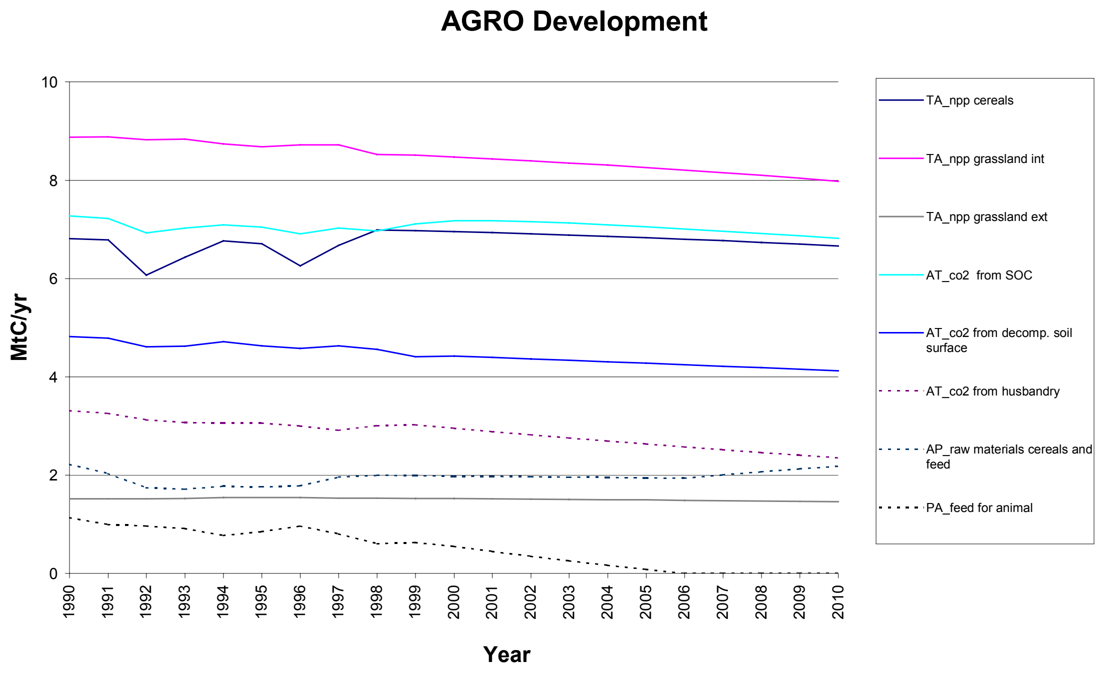
AE_biomass only includes straw and other unprocessed plant material for energy production by burning. Rape methyl-ester is synthesized in {PROD} and therefore allocated within the flow AP_raw material fats&oils. (analogue strategy was chosen for other biofuels). This is why the increase of AE-biomass is very moderate and amounts for only less than 0.15 MtC per year, although the reduction in feed demands from husbandry (see above) would suggest a steeper increase. AT_CO_2 from compost has an increase between 1999 and 2010 because of a higher input from {WASTE} to the process composting in {AGRO}. This higher input corresponds to a decreasing amount dumped in the landfills (for details see also {WASTE} Annex 6)

As a conclusion of NMC scenario results it can be stated that carbon flows of Austria's agriculture are comparatively constant over the modeling time frame indicating the relative equilibrium state of the production systems.

A 2-3.3 Scenario: Towards sustainability

In the TS-scenario we adopted several assumptions to guide the agricultural module into the direction of more sustainability.

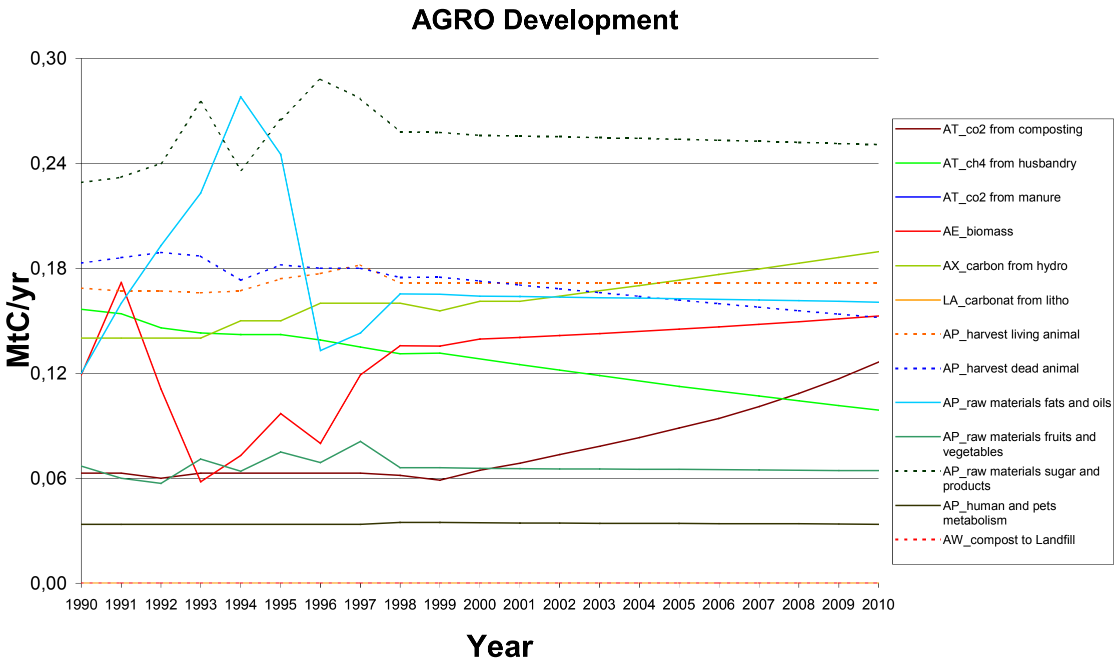
Figure A 2-10: Fluxes from and to the Atmosphere associated with the {AGRO} module – Scenario "Towards Sustainability" (TS)



The above figure shows the result of a higher increase in land use change between {AGRO} and {FOREST} for afforestation. This causes the greater decrease in net primary production of grassland and cropland *(TA_npp grassland int, TA_npp grassland ext* and *TA_npp cereals)* and a marked decrease in CO_2 emissions from soil, as these areas from the moment of conversion on are treated in {FOREST} (see above), and therefore the beneficial influence of this measure can only be seen in the final results of ACBM. In the figure it is well shown that in this scenario we assume a stronger decrease of the beef consume in Austria. This causes a more pronounced decrease of the CO_2 and CH_4 emissions from the agriculture because of smaller cattle stock sizes.

The flow *PA_feed for animals* is the interface flow from {PROD} to husbandry. The reduction in feed demand leads to the assumption that from the year 2006 onwards all feed for husbandry is produced locally without any need for additional feed imports. At the same time the flow *AP_raw materials cereals/feed* starts to increase according to the fact that reduced beef consume causes an increased demand for vegetable human foodstuff and more harvested plants can be sent to the {PROD}.

Figure A 2-11: Minor Carbon flows from {AGRO} to other modules in Scenario "Towards Sustainability":



The decrease in beef meat consume as discussed above is also noticed in *AP_harvest dead animal*. The flow *AP_harvest living animals* according to the expected unchanged consumption of milk and eggs remains at a constant level. A considerable decrease can be noticed for the flow *AT_CH_4 from husbandry* this is because of the lower cattle stock and the resulting lower enteric fermentation emissions of the cattle. Reduction in beef consume are partly compensated by increases in the consume of poultry meat. As methane production is a specific feature of ruminant digestion only, this shift in animal species additionally reduces *AT_CH_4 from husbandry.*

The flow *AE_biomass* from {AGRO} to {ENERGY}, biomass for energy production, increases between the year 1999 and 2010. mainly because of an assumed higher production of biogas. The production of straw is slightly decreasing because extensification leads to a moderate reduction in biomass production.

AT_CO_2 from compost has an strong increase between 1999 and 2010 because of a higher input from {WASTE} to the composting process in {AGRO}. This higher input is a reaction to the comprehensive fulfillment of the waste legislation and in parallel results in a decrease of the carbon flow to landfills (for details see also {WASTE} Annex 6).

A 2-3.4 Sensitivities and Uncertainties

A 2-3.4.1 Sensitivity Analysis

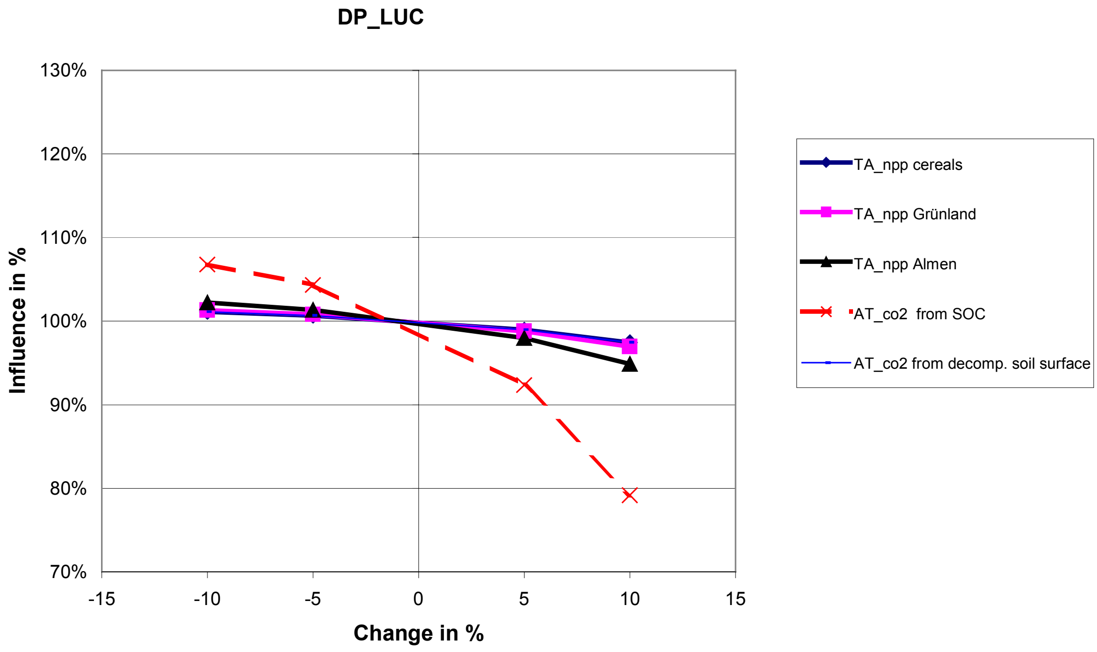
Sensitivity analysis was performed to investigate how a change of one driving parameter in the year 2000 influences the flows to the atmosphere at the modeling endpoint in the year 2010.

The following figures show those driving parameters which turned out to perform the strongest influence on modeling results of the {AGRO} module.

Land use change for the establishment of forests is one of the options discussed for the net reduction of CO_2 emissions to the atmosphere. According to the huge pool size of soil organic matter and associated CO_2 emissions via humus decomposition, a variation in the extent of land use change is most striking for the flow *AT_*CO_2 *from SOC* (see Figure A 2-12). Again, not system dynamics, but model calculation strategy is responsible for this effect, and changes in carbon emissions due to land use change can only be quantified as synthesis of forest and agro modeling results.

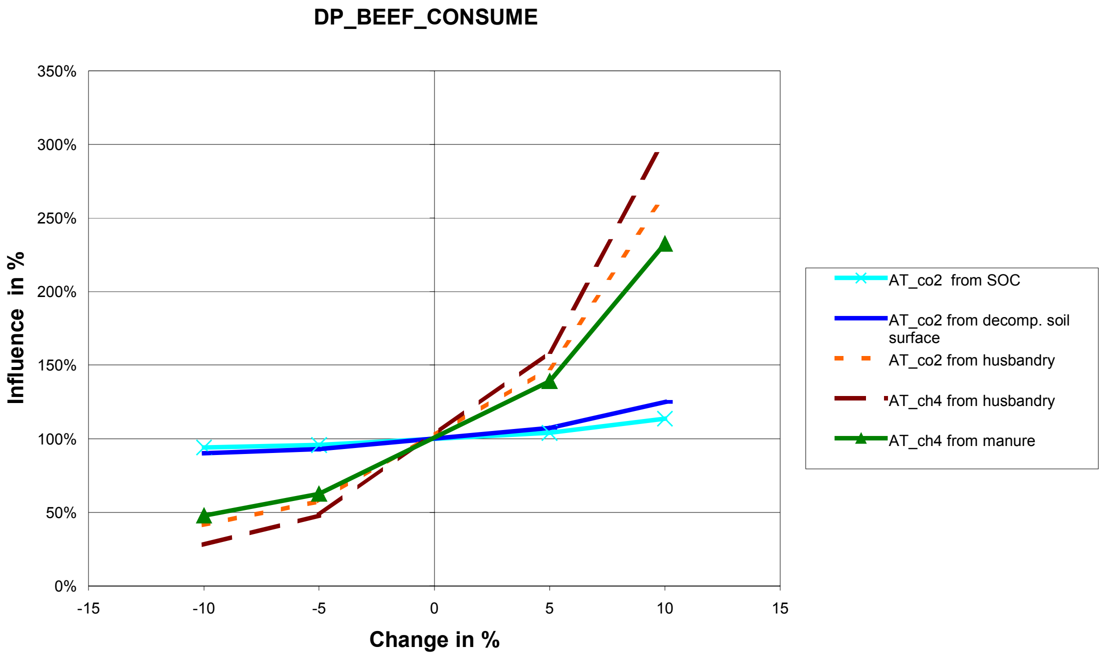
The afforested land is taken from all three types of agricultural land in a ratio of 30 : 50 : 10 for intensive grassland : extensive grassland : cropland. Accordingly NPP of extensive grassland is more sensitive to land use changes. All other flows investigated showed only moderate reactions to a variation of the driving force below 5 % in both (plus/minus) directions. *DP_LUC* (land use change) has a negative influence of the flows to the atmosphere, this means an increase in LUC causes a decrease in the flows to {ATMO}.

Figure A 2-12: Influence of Land use change on carbon flows between {AGRO} and the atmosphere



The driving force "beef consume" turned out to perform the highest impact on agricultural carbon flows from all adopted driving forces. Methane emissions from husbandry *(AT_CH_4 from husbandry)* raise by a factor of 3 if beef consume is increased by 10%. Methane emissions from manure management and CO_2 flows to atmosphere due to animal respiration are more than doubled. Comparatively small, but still relevant positive reactions of about 5 – 20% were noticed for CO_2 emissions as a consequence of manure application on agricultural soil surfaces and introduction into soil organic pools. These flows are increased because increased demand for beef meat causes an increase in the stock of living animals and consequent higher amounts of manure, which have to be disposed on agricultural land. The fertilization effect leading to improved plant growth and NPP is of small size only. Nevertheless, there exists a positive feedback loop between vegetation and husbandry (see A 2-5) which contributes to the extreme sensitivity of {AGRO} against changes in this driving force. In the opposite direction an intensification of trend to reduce beef meat consume by 10 % leads to a 50% reduction of both CO_2 and CH_4 flows from {AGRO}. A similar reduction of CH_4 emissions from manure management is predicted as well.

Figure A 2-13: Influence of changes in beef meat consume on carbon flows between {AGRO} and the atmosphere.



A 2-3.4.2 Uncertainties

Statistical data about agricultural production are routinely assessed and have to fulfill certain quality criteria . For the reporting on living animal stocks the number of observations is extended to achieve a maximum error of less than 5%, e.g. for pigs in 1999 uncertainty was 1.19 % *(Neumann, ÖSTAT; personal communication).* In the case of field crops harvest amounts are derived on the basis of reports from more than 2000 individual reports and weighted according to the size of the cropped area to which the reported result is referring (because larger continuous areas are more precise than smaller area results). Thus average uncertainty can be less than 5% *(Bader, ÖSTAT, personal communication).*

Moreover the precise quantification of harvested amounts, cropped area etc. more or less directly is linked to economic interests (e.g. support payments), and therefore, both farmers and authorities are interested in accurate reporting of agricultural data.

For data quality evaluation it is necessary to distinguish between data accuracy, which can be assumed to be quite good for production data and data variability. The consistency or annual results is disturbed by several external factors like weather conditions or market demands and prices. This intrinsic data variability cannot be reduced, but by calculation of mean values a good description of average harvest amounts is possible.

In the case of soil carbon derivation quite a number of assumptions had to be made; regional differences and a variety of applied analysis methods bring additional uncertainty into the data. For an estimation of overall uncertainty of derived “best estimates” of carbon stocks, the partial error of each calculation or assumption step was considered and processed by error propagation method.

Following partial errors were considered for 0-20 cm depth: confidence interval of medians in C_{org} concentration data: 10% (representative for extensive grassland, due to higher number of observations this value was lower for extensive grassland = 5% and cropland 3%)

skeleton content: 30%

soil density: 20%

analysis method correction: 20% (i.e. that chosen correction factors are too small/high)

conversion of humus values to Corg values (division by 1.724) : 10%

land use in federal countries: 5% (reporting on land use includes only areas greater than 1 ha)

under application of squared error sums $\boxed{\varepsilon_{tot}=\sqrt{\sum(\varepsilon_1^2+\varepsilon_2^2+\varepsilon_3^2+\varepsilon_n^2}}$

an overall (conservatively estimated) uncertainty of 44% must be assumed for soil carbon stocks in 0-20 cm depth.

For the interpretation of changes in soil derived carbon flows this considerable uncertainty must be kept in mind! Moreover an improvement of data accuracy in calculated soil carbon stock sizes, comparable to plant production data etc. is not feasible, because no repeated measurements are available at the moment for the derivation of confident random sample errors.

A 2-4 Discussion and Conclusions

A 2-4.1 Discussion

Due to practical reasons a model of a “real system” has always to be a simplification and often only the reduction of the complexity enables to understand the dynamics of the system.

The system dynamics of the module {AGRO} is defined by two major characteristics: although far apart from being an undisturbed ecosystem at present only moderate long term trends can be observed to influence Austria's agriculture. Nevertheless, on a disaggregated level and if short time scales are considered, external influences like weather conditions lead to a high data variability.

For the modeling of soil carbon stocks and dynamics due to the lack of time series data it was necessary to adopt the assumption of equilibrium status. Due to the large stock sizes this assumption has strong influence on uncertainty of modeling results referring to $C0_2$ emissions to the atmosphere.

A 2-4.2 Applicability of results

To use the model in the "right way" it has to be asked for what purpose is the model useful. The users must critically assess the model's boundary, time horizon, and level of aggregation in light of their purpose. The model boundary determines which variables are treated endogenously, which are treated exogenously, and which are excluded altogether. For example the module was build to simulate over the time span 1990 to 2010 and for this period the parameter are assumed. An extension of simulation time to the year 2020 would need a correction in the current assumptions of the driving parameters. Climate changes are not included endogenously, but by the use of measured data from 1990 to 1998 for the prediction of the future past climatic events are implicitly incorporated in the model projections. The big advantage of our model is that it is not overloaded with complexity and it can more or less easily be "validated" and retuned by new statistic data in the future, for example the trend in the NMC scenario can be corrected in the year 2005 or new legislative regulations could be incorporated by a redefinition of driving parameters if necessary.

A 2-4.3 Priorities for future work

In the framework of this project it became evident, that the interdependencies between carbon and nitrogen cycle should be represented in the AGRO modeling system. This would offer new opportunities for the incorporation of management practices within the model.

Moreover following items were identified for possible further development of the AGRO module:

- Spatial datasets about soil carbon contents at appropriate resolution would be highly desirable for the reduction of uncertainty associated with the quantification of SOM stocks in different regions of Austria.
- Soil organic matter pools play a major part in determining the physical properties of soils such as resistance to erosion. This factor was only very roughly estimated in ACBM and could be improved by incorporation of spatially explicit methods and a DEM (digital elevation model).
- Predicting the longer-term impacts of directional environmental change (e.g. warming, CO_2 increase in atmosphere) on SOM turnover and plant production (NPP) is currently limited by shortage of quantitative data from longer-term field-based manipulations of semi-natural ecosystems like meadows *(Sutton et al. 2000).* For quantitative evaluation of Austrian specific conditions, an incorporation of long-term field experiments about agricultural soil management practice would be desirable.

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Annex 3

ACBM Modul
ENERGY

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Table of Contents

A 3-1 Introduction

The carbon emissions from energy use have a significant influence on the increasing carbon concentration in the atmosphere, that may lead to global warming. The combustion of fuels leads to the oxidation from carbon to carbon dioxide (CO_2). The carbon in the fuel mainly determines the heating value of the fuel. The CO_2 emissions from fossil fuel combustion leads to a increasing concentration of carbon in the atmosphere. The combustion of biomass leads also to carbon emissions, but this carbon was previously fixed in the biomass by photosynthesis. If biomass comes from sustainable management, the carbon cycle of the energetic use of biomass is considered to be closed (IPPC 1997).

The carbon in oil, gas and coal is taken from the resources in the lithosphere and the carbon in biomass is taken from biomass in forestry and agriculture. In the energy system no carbon is stored for a longer period, that means that the storage of fuels now and then has no real influence on the carbon flow in the system, as it is assumed here.

In Austria the primary energy demand is about 1,200 PJ/a, where about 75% are fossil fuels - oil, gas and coal - and 25% are renewable energy - hydro power (13%) and biomass (12%). The CO_2-emissions in the Austrian energy system from the combustion of fossil fuels are about 60 Mio. t/a.

The interfaces to the other modules are characterised in three main groups:

- biomass from the other modules to {ENERGY},
- energy demand for energy services from the modules to {ENERGY} and
- raw materials from energy carriers from {ENERGY} to {PROD}

A 3-2 Methodology

A 3-2.1 Data availability

Many data are available from energy statistic for the years 1990 to 1998, that are used for the modelling of these years (Energieverwertungsagentur 1991, Energieverwertungsagentur 1992, Energieverwertungsagentur 1993, Energieverwertungsagentur 1995, Energieverwertungsagentur 1995a, Energieverwertungsagentur 1997, BMwA 1992, BMwA 1993, BMwA 1993a, BMwA 1994, BMwA 1994a, BMwA 1996, BMwA 1996a, BMwA 1997, BMwA 1998, BMwA 1999, ÖSTAT 1992, ÖSTAT 1993, ÖSTAT 2000).

Beginning with 1999 many assumptions are necessary for the data and the development of the energy demand and supply system. The basic data are given by the "NUP-energy model" used in the Nationaler Umweltplan Österreich (NUP 1996). These data of the development of the Austrian energy system were discussed and fixed with economic experts from WIFO (Kratena 2000).

The modelling needs two different types of data: one for the situation in the past with "real" data and one for the future situation with "estimated" data. This means for the modelling that there is a possibility to update the model in future easily when new statistic data will be available.

A 3-2.2 Data and knowledge gaps

To model the carbon system in the energy sector it is necessary to model the energy system first, that means the energy transformation from primary energy to the supply of energy services. Once the energy system is fixed, the carbon flows in the energy systems are modelled by identifying the energy flows, which are connected with a carbon flow. These energy flows are biomass, coal, oil and gas. The conversion from energy to carbon flows is done by using the heating value and the carbon content of the different fuels to calculate the conversion factor of carbon per PJ (unit: MtC/PJ). The heating value and the carbon content of oil and gas are quite stable, but for coal and biomass they might change from year to year. In addition to heating value and carbon content the conversion factor for biomass depends of the kind of biomass, if it is bark, wood chips, biogas, waste etc. In {ENERGY} the different kinds of biomass are not distinguished. The conversion factors use are:

- oil: 0.021 MtC/PJ,
- gas: 0.015 MtC/PJ
- coal, that is a mixture of lignite, hard coal and coke: 0.025 – 0.027 MtC/PJ and
- biomass, that is a mixture of bark, fuel wood, wood chips, lye, biogas, methylester and waste: 0.025 – 0,027 MtC/PJ

Therefore the details of the energy system determine the details of the carbon system in the energy sector. So the available energy data influence the modelling approach of the carbon system.

A 3-2.3 Model design

General

The main guideline of the development of the concept of {ENERGY} is to follow the outline of the energy flow figure of the Austrian energy system, which is annually published by the Energieverwertungsagentur (Figure A 3-1) (Energieverwertungsagentur 1991, Energieverwertungs-agentur 1992, Energieverwertungsagentur 1993, Energieverwertungsagentur 1995, Energieverwertungsagentur 1995a, Energieverwertungsagentur 1997). The modelling concept is also closely related to previously developed modelling concepts (Wohlgemuth 1992, NUP 1996).

Also the data availability determinates the modelling. This means, that all energy related emissions from energy use in the other modules is included in {ENERGY}, because the statistic data are not available in a common format for the different sectors i.e. {FOREST} and {AGRO} are not separated (ÖSTAT 1992, ÖSTAT 1993, ÖSTAT 2000).

Visualisation of model structure

In Figure A 3-2 the overall design of the {ENERGY} model is shown. In Figure A 3-3 the details of the energy services, in Figure A 3-4 the details from primary energy to useful energy and in Figure A 3-5 the details from primary energy to final energy are shown.

The {ENERGY} module starts on the left side with the 4 primary energy carriers - biomass, coal, gas and oil - its transformation to the 6 final energy carriers in the middle – biomass, coal, gas, oil, electricity and heat - until it ends on the right side with the 5 different types of useful energy:

- mechanical work,
- process heat,
- space heat,

- vehicles and
- light.

The useful energy is allocated to the 3 main demand sectors

- industry,
- residential and
- transportation.

The transformation steps are refinery, cooking plant and blast furnaces that are also parts of {PROD}, but are traditionally handled in {ENERGY}. Further transformations steps are power plants, combined heat and power (CHP) plants as well as heating plants for heat and electricity production.

The energy module is driven in principle from the demand of energy services, which determines the demand of useful energy on the left side of Figure A 3-2 and details in Figure A 3-3. The duty of {ENERGY} is to satisfy the energy demand by using different energy resources (primary energy). The energy demand is predefined by the other modules {PROD}, {WASTE}, {AGRO} and {FOREST} and "transportation". Whereas “transportation” is part of {ENERGY}. The modules {PROD} and {WASTE} are in the "industry sector", the modules {AGRO} and {FOREST} are part of the residential sector and transport is in the transportation sector.

The other modules give biomass to {ENERGY}, for which the information about the kind of biomass, carbon content, heating value are necessary and given by the other modules.

The flows of carbon from {ENERGY} to {ATMO} occur in the transformation from

- primary energy to final energy from refinery, cooking plant and blast furnaces, power plants, combined heat and power plants, heating plants and losses from the distribution of gas (includes energy demand for gas distribution);
- final energy to useful energy from mechanical work, process heat, space heat, vehicles and light.

The interfaces to the other modules are

- {WASTE}: biomass from {WASTE}, ashes to {WASTE}, energy demand from {WASTE}
- {FOREST}: biomass from {FOREST}, energy demand from {FOREST};
- {AGRO}: biomass from {AGRO}, energy demand from {AGRO};
- {PROD}: biomass from {PROD}, gas and chemicals to {PROD}, energy demand from {PROD};
- IMP/EXP: biomass, oil, gas, coal, electricity from/to {IMP/EXP}.

Within {ENERGY} different types of data can be distinguished:

- carbon flows, (i.e. EE_gas process heat)
- energy flows and (i.e. EE_electricity light)
- driving parameters (i.e. DPE_useful energy mix industry).

The carbon and energy flows are closely connected to each other, and each carbon flow is connected with an energy flow but not each energy flow is connected with a carbon flow i. e. WE_biomass is connected with (WE_biomass), but (EE_electricity CHP plant) has no carbon flow, because electricity is not connected with carbon (Figure A 3-6).

The driving parameters are used to run the model. The 4 most important groups of driving parameters are

- development of the energy services,
- development of energy efficiencies (conversion efficiency, energy productivity),

- mix of fuels and final energy carrier and
- mix of final energy used in different sectors.

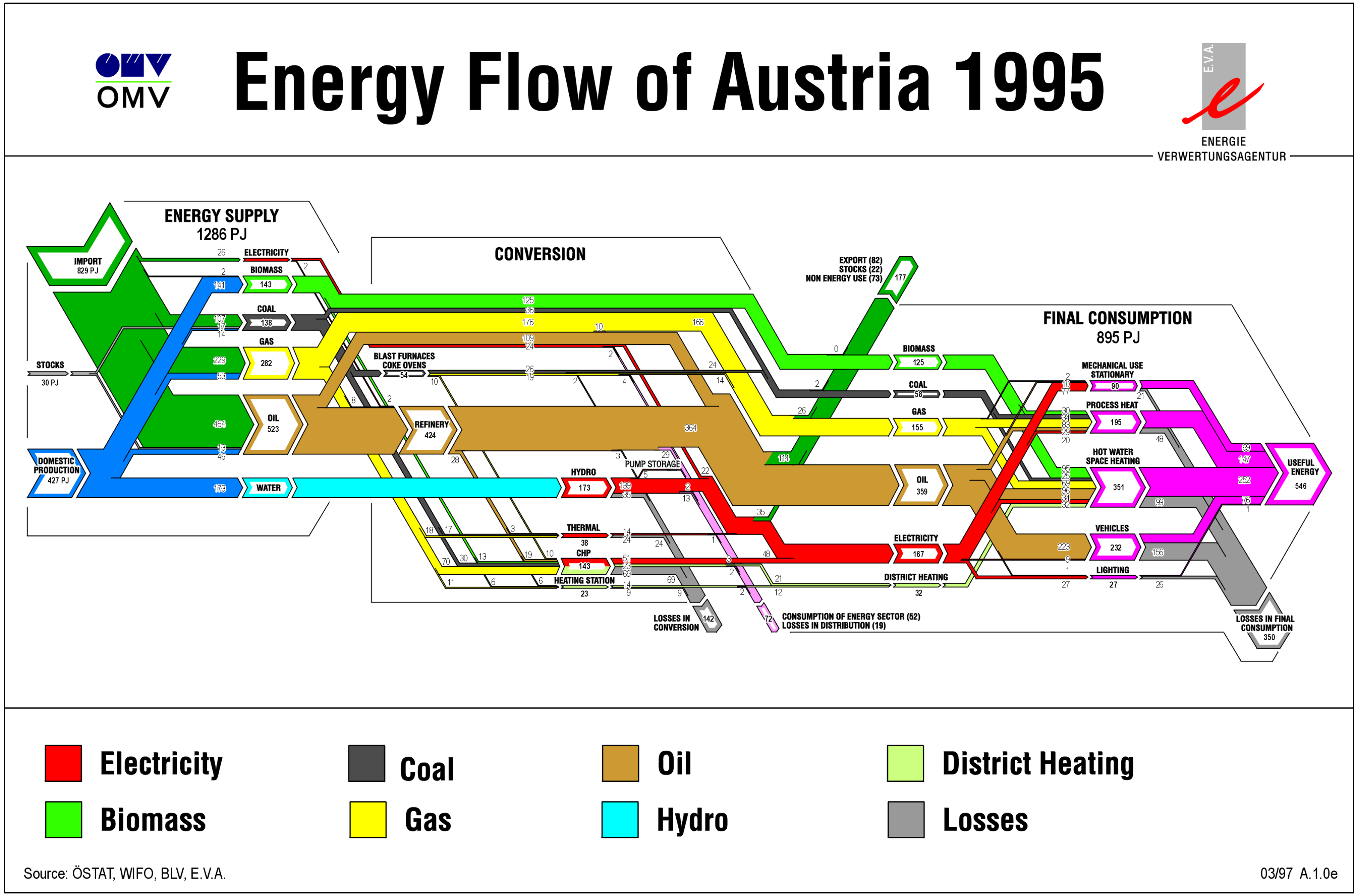
Driving parameters are defined according to the “Driving Force” scenarios and described in further detail under chapter 3-2.4

Treatment of CH_4 and VOC

The treatment of methane (CH_4) and other volatile organic compounds (VOC) are described. Flows of CH_4 are and flows of VOC are not considered in {ENERGY}.

In the Austrian inventory the total CH_4-emission is about 650,000 t/a (Ritter et al. 1999), which corresponds to a carbon flow 0.487 MtC/a. About 5% of this carbon flow in CH_4 is caused by the energy system, that are 0.024 MtC/a. The main sources of CH_4 occurs from combustion processes and from losses in the natural gas distribution system. That means for {ENERGY}, that the carbon flows ET_process heat, ET_space heat, ET_vehicles and ET_loss gas have a small fraction of CH_4. These 4 carbon flows cover about 98% of the CH_4 emissions from {ENERGY}, therefore only these 4 carbon flows are divided in carbon flows for CO_2 and for CH_4. The modelling is done with driving parameters that give the shape of CO_2 and CH_4. Because of technical improvement of combustion processes it is assumed, that the CH_4-fraction on the 4 affected carbon flows has a small decrease in future.

Figure A 3-1: Energy flow of Austria 1995 (Energieverwertungsagentur 1997)



Source: ÖSTAT, WIFO, BLV, E.V.A.

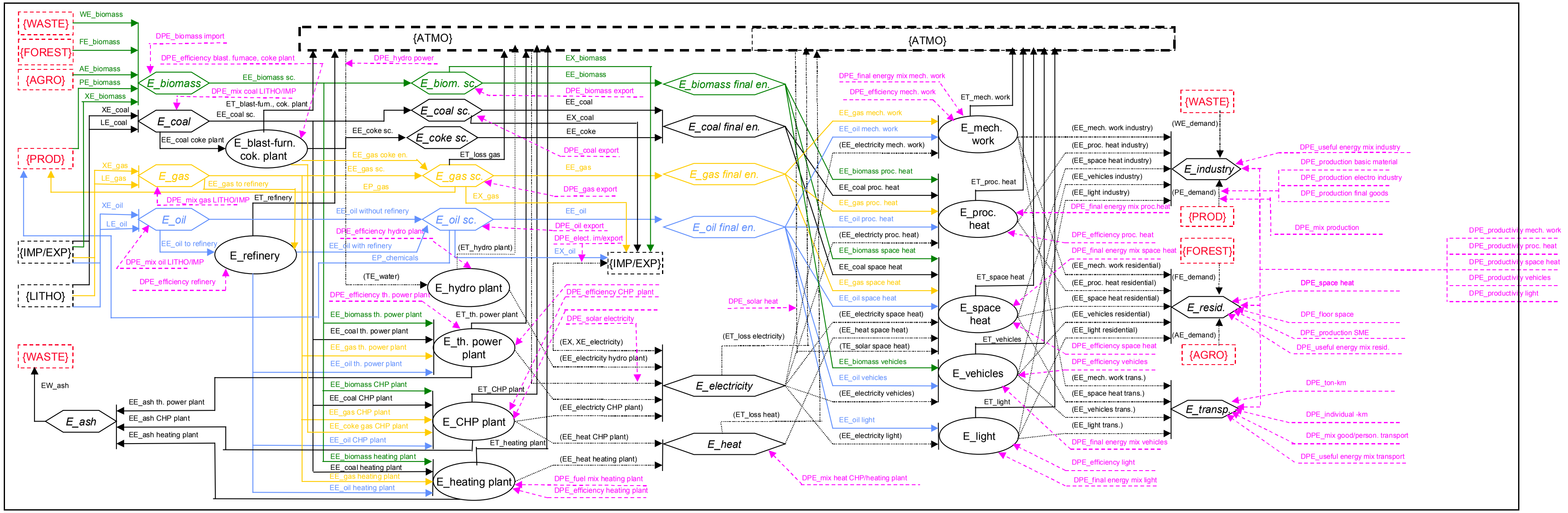


Figure A 3-2: Concept of the {ENERGY} module (overview)

Figure A 3-3: Concept of {ENERGY} Model – details energy services

Figure A 3-4: Concept of {ENERGY} Model – details final energy to useful energy

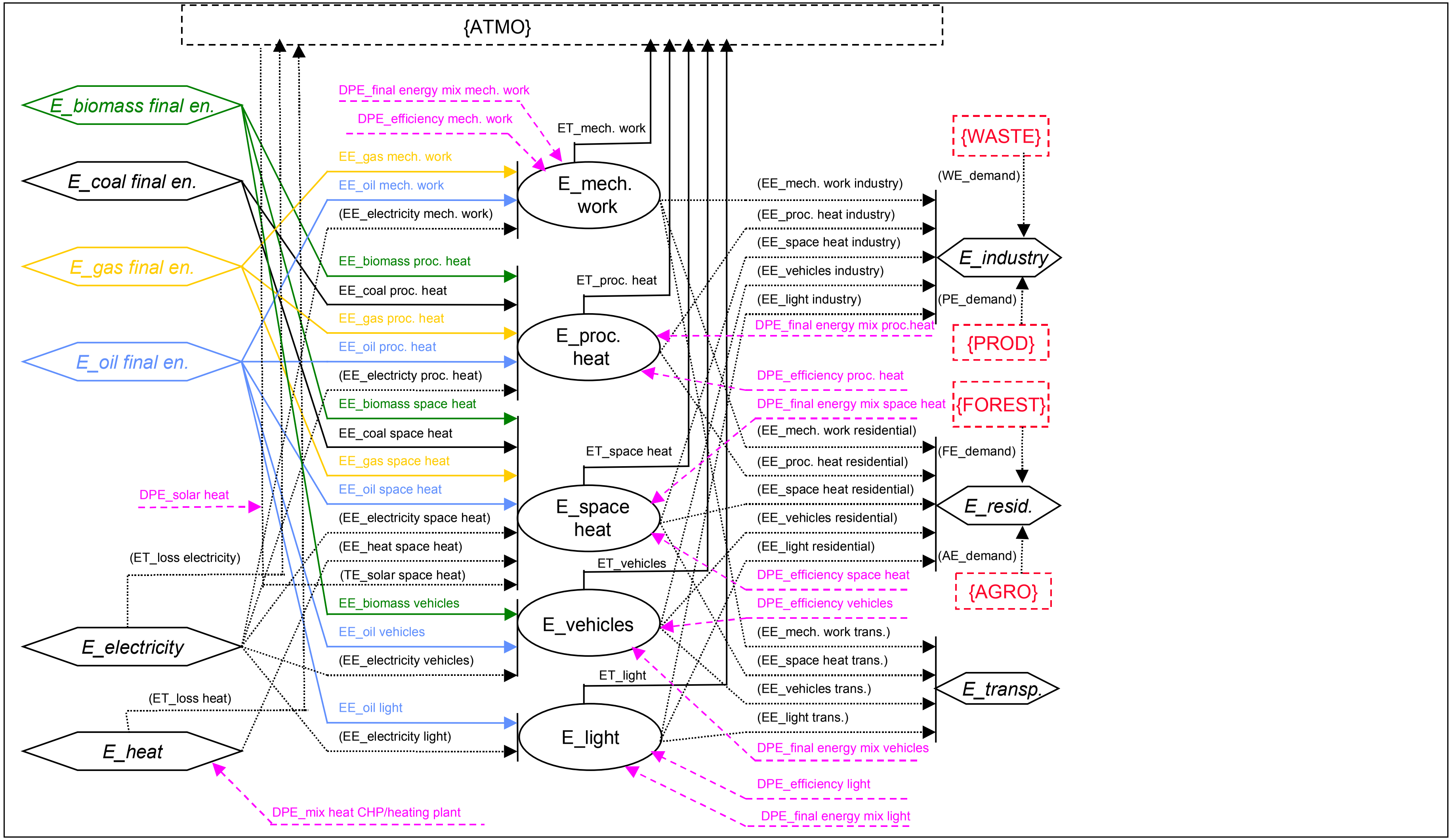


Figure A 3-5: Concept of {ENERGY} Model – details primary energy to final energy

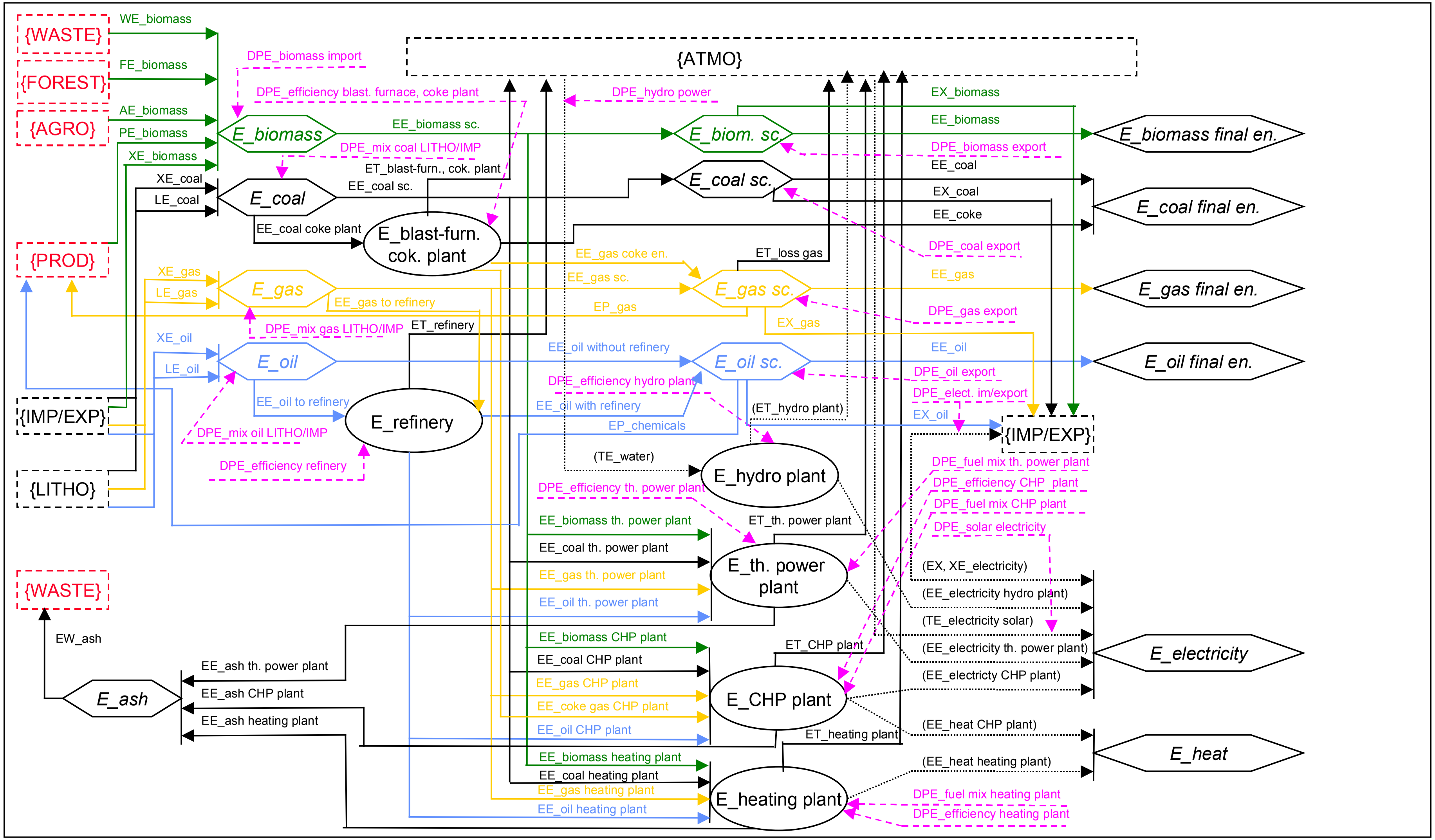
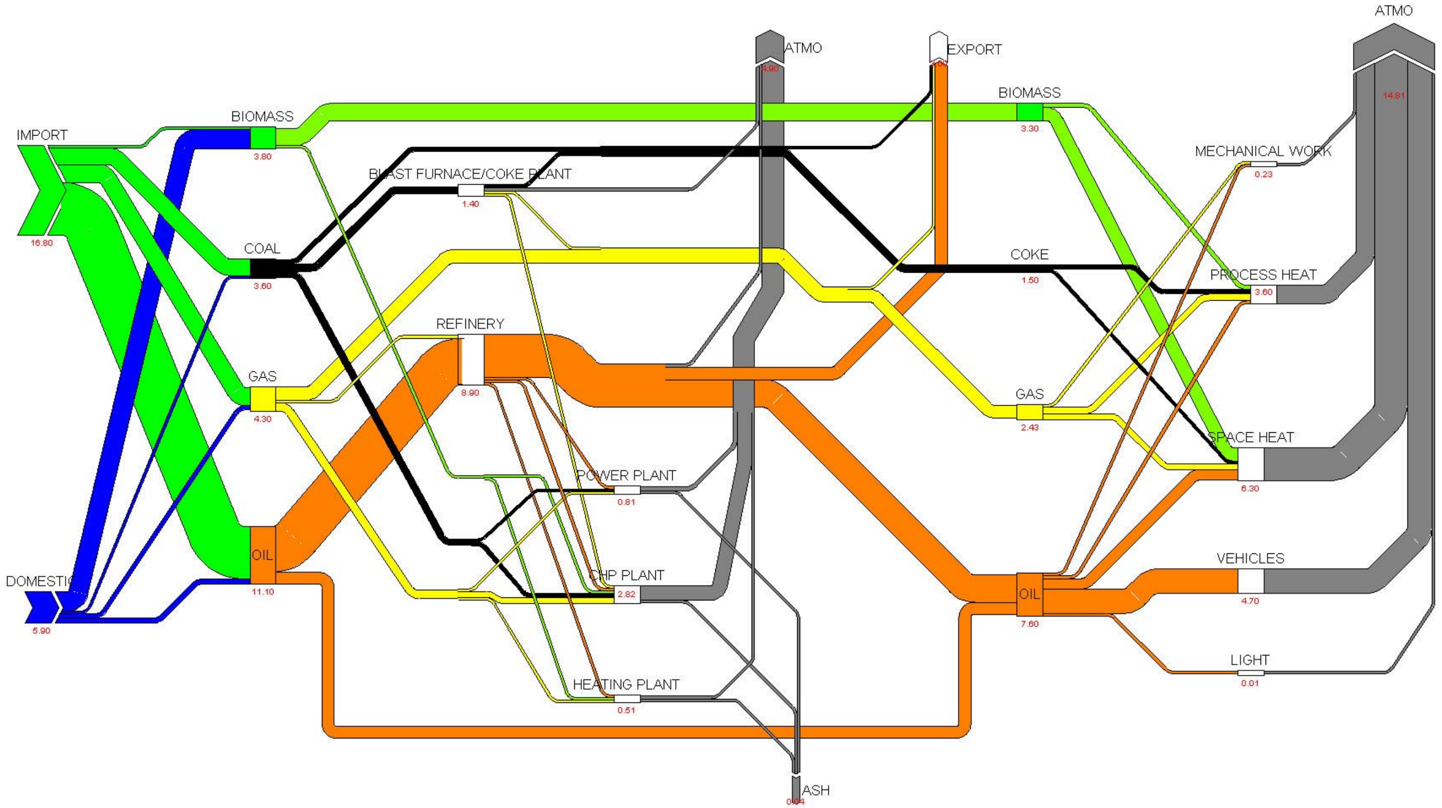


Figure A 3-6: Carbon flow of Austria 1995 (results of {ENERGY})



Calculation procedure

The demand of energy services in the 3 sectors – industry, residential and transportation – determine the need of useful energy – mechanical work, process heat, space heat, vehicles and light. The amount of final energy is calculated by using the different efficiencies of the final energy carriers - biomass, coal, gas, oil, electricity and heat - and the shares of the different final energy carrier for the different kinds of useful energy. The demand of electricity and heat is satisfied by hydro and solar plants (photovoltaic and wind), thermal power plants, heating plants and CHP plants, by taking the different efficiencies and share of fuels into account. The total amount of primary energy is calculated as the sum of fuels as final energy carrier and as fuels for electricity and heat production, by taking the refinery of oil, the coke plant and the blast furnace into account. With the share of imported fuels and domestic fuel production the amount of energy and carbon from the other modules is calculated.

The most important driving forces for the future development of the energy demand are determined by the (compare to Wohlgemuth 1992 and NUP 1996)

- need of energy services,
- productivity of the useful energy and
- development of efficiencies of energy transformation (from useful energy to primary energy).

These important driving parameters differ in the two scenarios “no major changes” (NMC) and “towards sustainability” (TS).

Following the concept in Figure A 3-2 the energy module is modelled including the official data of energy statistic. For the period of 1990 to 1995 the energy module contains the data according to the annual published Austrian energy flow.

Need of energy services

In dependence of the 3 sectors the need of energy services is mainly determined by the following driving parameters, that describe the future economic development (Figure A 3-7)

- industry: production basic materials, production electro-chemical industry and production of final goods
- residential: development of floor space and production of small medium enterprises (SME)
- transportation: development of ton kilometre (ton-km) and of individual kilometre

As decided for the whole ACBM-model the development of inhabitants is not taken into consideration. These 7 driving parameters for the future need of energy services are indicated to 100% in the base year 1995, the last year with real data from energy statistics.

Productivity of the useful energy

The development of the productivity of useful energy is defined for each kind of useful energy – mechanical work, process heat, space heat, vehicles and light (Figure A 3-8). These 5 driving parameters of productivity are indicated to 100% in the base year 1995, the last year with real data from energy statistics.

Development of efficiencies of energy transformation

The development of the efficiencies of transformation, which means all transformation steps from useful energy via final energy and secondary energy to primary energy, influences the future energy supply system. Examples are given for the transformation from useful energy to final energy in Table A 3-1.

Figure A 3-7: Development of the need of energy services in the two scenarios (“no major changes, NMC, “towards sustainability” TS)

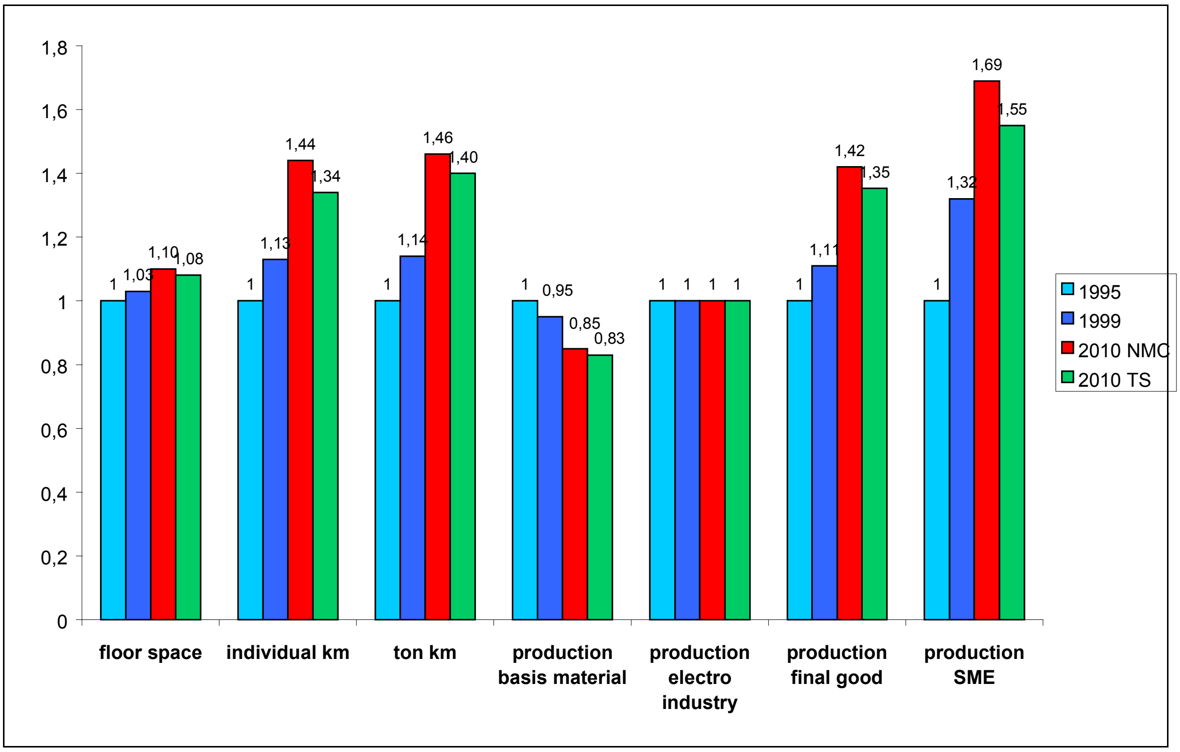


Figure A 3-8: Development the productivity of the useful energy in the two scenarios ("no major changes, NMC, "towards sustainability" TS)

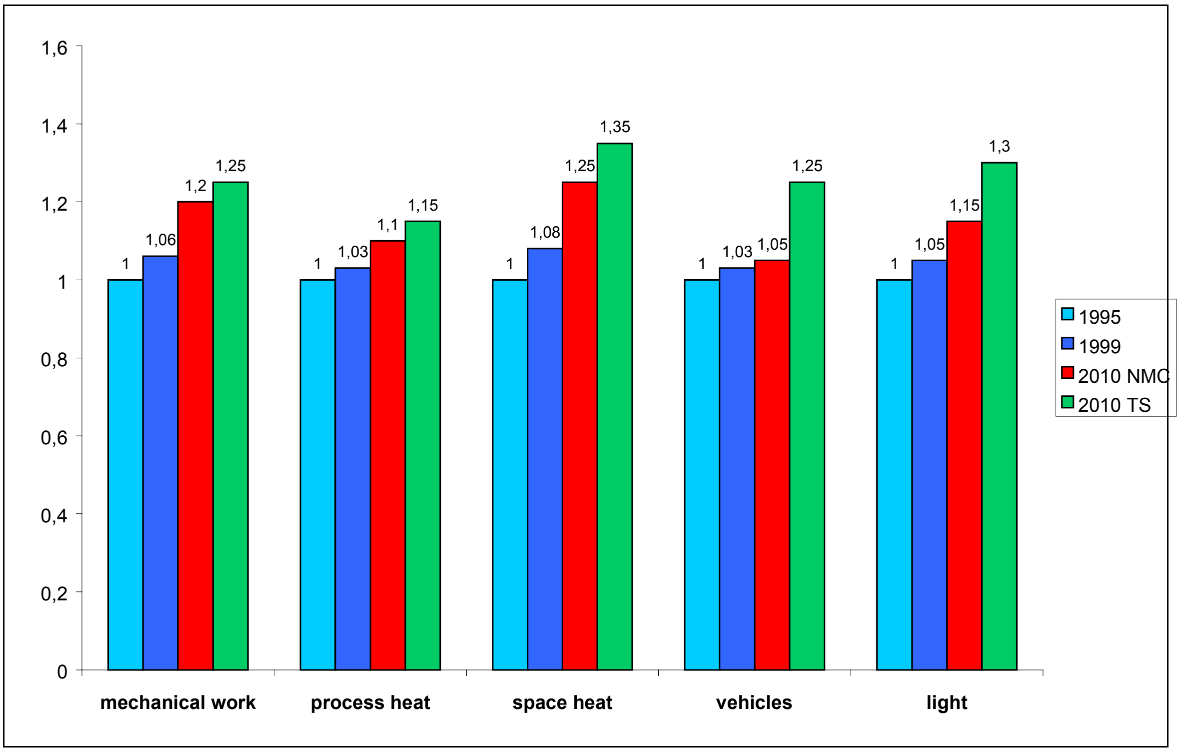


Table A 3-1: Development of efficiencies of energy transformation from useful energy to final energy

		1990	1999	2010 NMC	2010 TS
mech. work	oil	35%	35%	35%	37%
	gas	35%	35%	36%	37%
	electricity	85%	85%	86%	87%
proc. heat	coal	70%	72%	73%	75%
	oil	75%	75%	76%	77%
	gas	75%	75%	76%	78%
	biomass	73%	74%	76%	79%
	electricity	90%	90%	91%	92%
space heat	coal	55%	55%	55%	55%
	oil	75%	75%	76%	76%
	gas	70%	73%	75%	78%
	biomass	61%	62%	64%	70%
	electricity	88%	89%	90%	92%
	heat	95%	95%	95%	95%
vehicles	oil	30%	30%	30%	31%
	biomass	30%	30%	30%	30%
	electricity	95%	95%	95%	95%
light	oil	3%	3%	3%	3%
	electricity	5%	5%	5%	6%

A 3-2.4 Scenarios

Two scenarios are analysed,

- scenario “no major changes” (NMC) and
- scenario “towards sustainability” (TS).

These two scenarios start in the year 1999, so the results from 1990 to 1998 are the same for both scenarios. In the NMC-scenario the current trends derived mainly from the year 1990 to 2000 are projected till 2010. In the TS-scenario a modification of current trends are modelled into the direction of a sustainable development.

A sustainable development for the Austrian energy system means in general,

- a high level of energy services with an increased reduction of useful energy,
- a high energy transformation efficiencies and
- an increased use of renewable energy.

The overall trend in the energy system is an increase of needed energy services. The final and primary energy needed to fulfil these energy services depends on the efficiency of the overall energy transformation. So in general the future need of energy depends on the development of energy services on one hand and the improving of energy efficiency on the other hand. Different trends in these developments are given in the two scenarios. In scenario “towards sustainability” the increase of energy services is more moderate than in the scenario “no major changes”, but the development of energy efficiency is more moderate in the scenario “no major changes” than in the scenario “towards sustainability”.

The modelling of these two scenarios is done via driving parameters (DP). Each driving parameter is part of a driving force (DF) and each driving force is part of a driving bag (DB) (details for this concept are described in the report). The relevant driving bags to {ENERGY} and their driving forces for {ENERGY} are shown in Table A 3-2. The complete list of driving parameter and their data for each scenario used in {ENERGY} is shown on the CD Rom (ACBM_Metadata base.xls) .

Table A 3-2: Driving bags and driving forces used in {ENERGY}

	NO MAJOR CHANGES (2000-2010)	TOWARDS SUSTAINABILITY (2000-2010)
DB ECONOMIC DEVELOPMENT	**Economic development will be around growth rates of 2,5 % GNP p.a. Contribution of agriculture to GNP will slightly decrease. Growth rates will mainly come from services and leisure tourism. Production will shift from primary to secondary products.**	**Economic development will be around growth rates of 2% GNP p.a. Contribution of agriculture to GNP will remain the same. Growth rates will mainly come from services and leisure tourism. Production will shift from primary to secondary products, with more products from renewable raw materials.**
DF Production	Continuation of current trends depending on the respective products.	Slight decrease in trend for fossils, increase in production of wood products.
DB ECONOMIC STRUCTURAL CHANGES	**Economy will shift from primary to tertiary sector. Increase of IT-based economy. Consumption of goods will increase. In energy sector shift from coal/oil to gas. 2 % increase per year of the area for extensive agriculture. Agricultural output remains almost the same. Cheaper world prices for electricity & increased imports of primary products, food, and feed.**	**Economy will shift from primary to tertiary sector. Increase of IT-based economy. Consumption of goods will increase. In energy sector shift from coal/oil to gas. Slowly increasing use of renewable energy sources. 4 % increase per year of the area for extensive agriculture. Agricultural output has an slight decrease due to the extensivation of agriculture.**
DF Final energy mix industry	Market shift from coal to gas; slight shift from oil to gas; increase of biomass use	All trends stronger
DF Final energy mix traffic	Slight shift to more electricity, biomass fuels 1%	Biomass fuels 2%
DF Final energy mix residential	Marked shift from coal to gas; slight shift from oil to gas; increase rate of biomass use; increase rate of solar energy by 2 % p.a.	less coal in 2010 in residential, less coal in power plant and industry shift from oil towards gas; increase of biomass use ; increase of solar energy by 4 % p.a.
DF Fuel mix	Marked shift from coal to gas; slight shift from oil to gas; increase rate of biomass; increase rate of solar energy by 2 % p.a.	less coal in 2010; shift from oil towards gas; increase of biomass; increase of solar energy by 4 % p.a.
DF Import / export behavior	more electricity imports because of liberalization.	Electricity from Austrian water power plants is favored; less imports
DF Mix of good/personal transport	Mix stays stabile	More transports than personal transports
DF Mix production	Final goods prod. will increase, basic materials decreases 1% p. a, electro-chemical industry remains the same, increase in final good production 2,5 % p. a.	Final goods prod. will have an lower increase, basic materials decrease 1 % p. a., electro chemical industry remains the same, increase in final good production 2 % p. a.
DF Globalization: imports/exports	Increase in ton km	Lower increase in ton km
DF Mix district heat	Increase of district heat from combined heat and power production	Stronger increase of district heat from combined heat and power production
DF Mix space heat	Coal has an decrease, biomass and district heat have a increase, gas increases too	Coal has an higher decrease, biomass and district heat have a higher increase, gas remains the same, oil decreases
DF Mix useful energy industry	Decrease of coal and oil, increase of gas and biomass	Stronger increase of coal and oil, stronger increase of gas and biomass
DF Use of other renewable	Hydro power remains, solar increase	Slight increase of hydro power, stronger increase of solar
DB LIFESTYLE	**Continuation of 1990-2000 rates of single households, environmental awareness, nutrition patterns, vehicle mileage. Increasing vehicle use for „fun“ matches decreasing commuting because of teleworking.**	**Continuation of 1990-2000 trends, but less vehicle use (decrease in annual vehicle mileage by 5 % until 2010), more environmental awareness, more vegetarians. Increase of natural forests by 2 % p.a.**
DF Urbanization vs. suburbanization	Strong increase of floor space per person and individual km per person	lower increase of floor space per person and individual km per person
DB TECHNICAL DEVELOPMENT	**Continuation of current trends**	**Increased efficiencies above current trends**
DF Energy efficiency	Continuation of current trends;	Increase of current trend
DF Energy productivity	Continuation of current trends	Increase of current trend

A 3-2.5 Model Formulation

The model formulation is done with Visual basic in EXCEL. The starting point was the account of the energy balance for the years 1990 to 1995 following the energy flow of Austria. Next step was the transformation of the energy balance in the carbon balance, by implementing the energy related carbon conversion factors for all carbon flows. The results of these steps were checked and adjusted with the official carbon emission inventory (Ritter et al. 1999). After this the development of the need of energy services was implemented. Further on the driving parameters were calculated for the period from 1990 to 1995 so far as possible and predicted for future development. After this the driving parameters were implemented for the two scenarios and the model was tested.

The plausibility was checked by making an energy and carbon balance for each process and each dispatcher each year. By regarding the development of single flows from 1990 to 2010 and their relation to each other helped to check the plausibility and the quality of the results by analysing absolute and relative changes. At least the fulfilment of certain expectations was proven. Further on the reproducing of special results was tested. The expected change of certain input/output relations was checked by parameter variation and sensitivity analyses (see chapter 3-5).

All energy flows are calculated for the same year. Even all carbon flow, except the biomass from forest (FE_biomass), are calculated for the same year. FE_biomass is the only carbon flow, which is taken from the previous year, because the energy need in biomass from forestry is calculated in the actual year. In the calculation of the conversion factor and the carbon balance the results from the same year are taken.

The limitations of modelling are given by the chosen model design and structure. This means i.e. a more detailed subdivision of the need of energy services for special economic sectors like pulp and paper industry is not possible. Further on the adaptation of the model for different scenarios needs experience in the understanding and in the possible development of the Austrian energy system. This means also that the model is not able to distinguish between realistic and unrealistic input parameters. The model has no limitations for the size of certain input parameters i.e. that the efficiency of one process cannot be higher than 100%. So the model has no automatic plausibility check of the input parameters. Summing up {ENERGY} is more an expert module than a model for wide common use.

A 3-3 Results

A 3-3.1 Dynamic model behavior

The dynamic model behavior of {ENERGY} is described with the results of the development of the Austrian energy system, whereas the useful energy, the final energy and the primary energy are described in detail.

Useful energy

In scenario NMC the demand of useful energy will increase (660 PJ/a), in scenario TS it will decrease (570 PJ/a) (Figure A 3-9). In both scenarios the development of the demand of useful energy is mainly influenced by the useful energy for vehicles in transportation sector and for space heat in residential sector (Figure A 3-10). The energy demand in industry sector is decreasing in both scenarios (Figure A 3-11), because of increasing productivity of useful energy and decreasing production of basic materials. The energy demand in transportation sector is dominated by vehicles and is only decreasing in scenario TS (Figure A 3-12), mainly because of higher productivity of useful energy. The energy demand in residential sector is dominated by space heat and is only decreasing in scenario TS (Figure A 3-13).

Figure A 3-9: Results of dynamic behaviour of the need of useful energy in end use categories

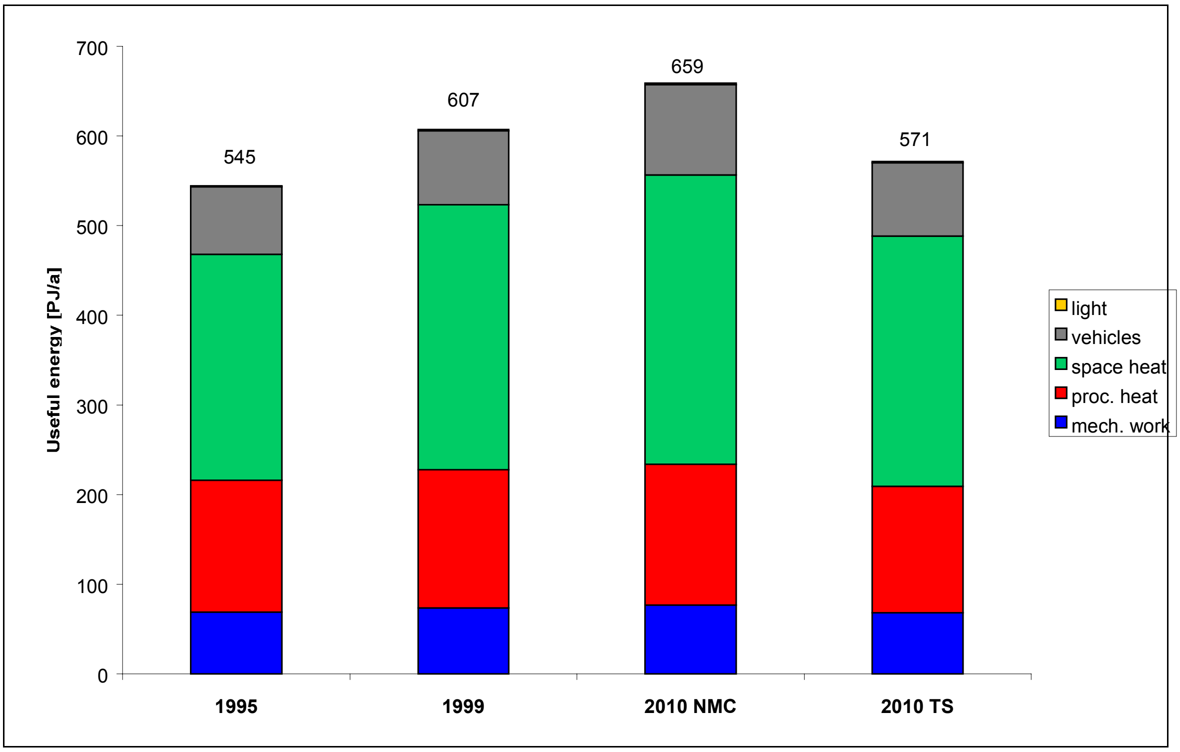


Figure A 3-10: Results of dynamic behaviour of the need of useful energy in the three user sectors

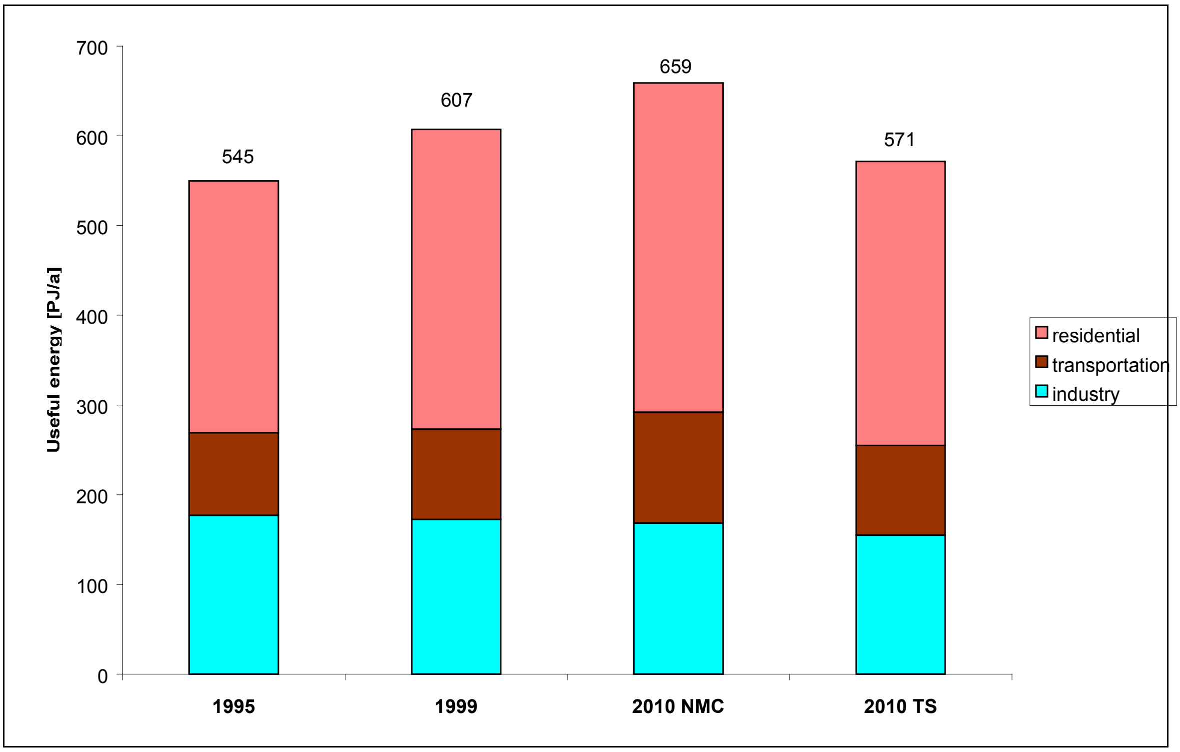


Figure A 3-11: Results of dynamic behavior of the need of useful energy in the industry sector

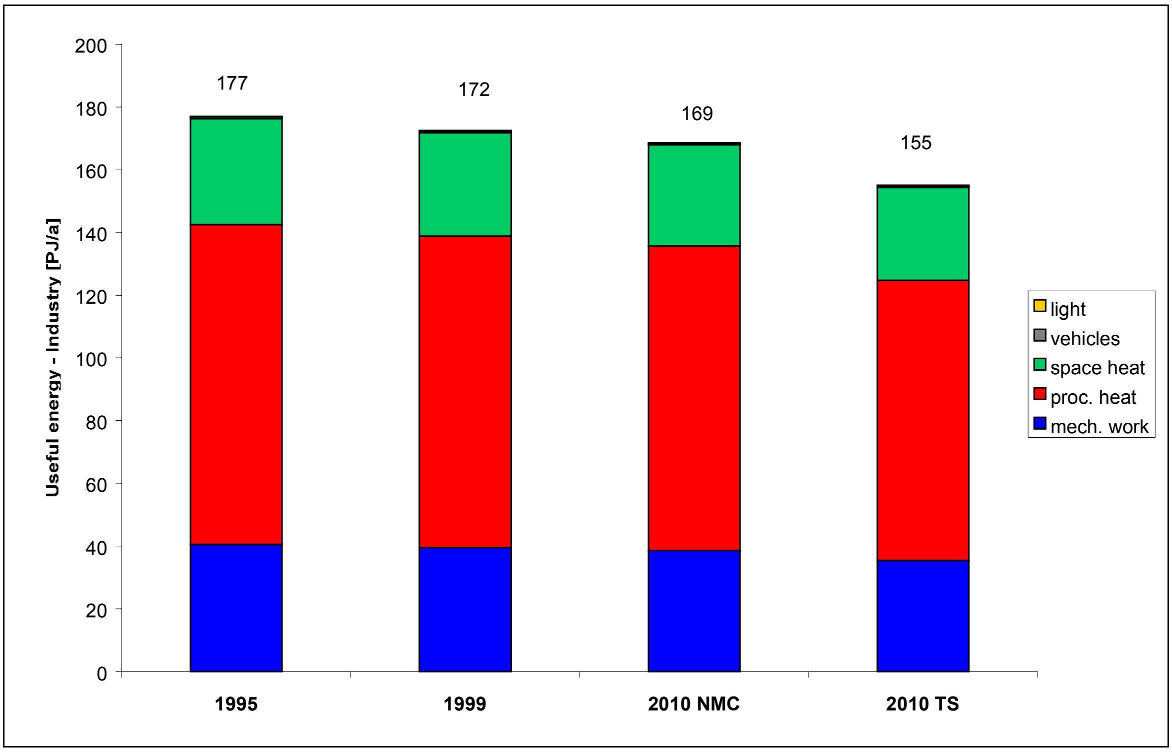


Figure A 3-12: Results of dynamic behavior of the need of useful energy in the transportation sector

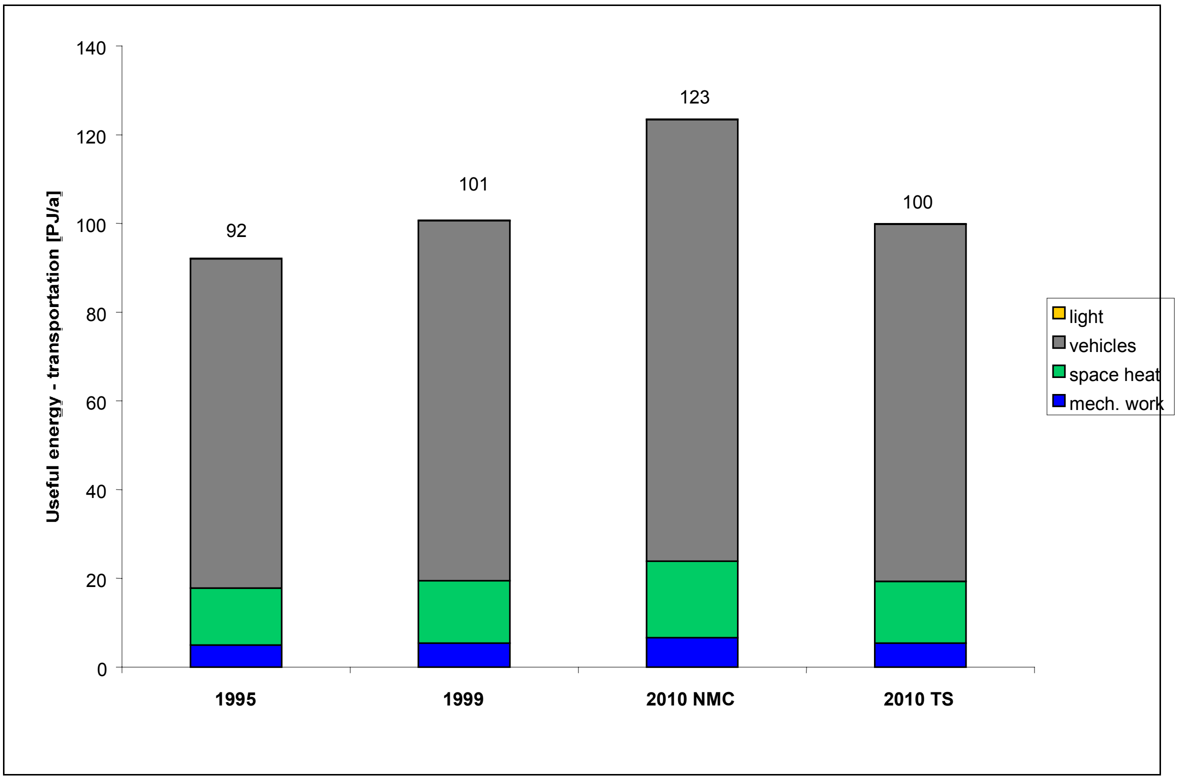
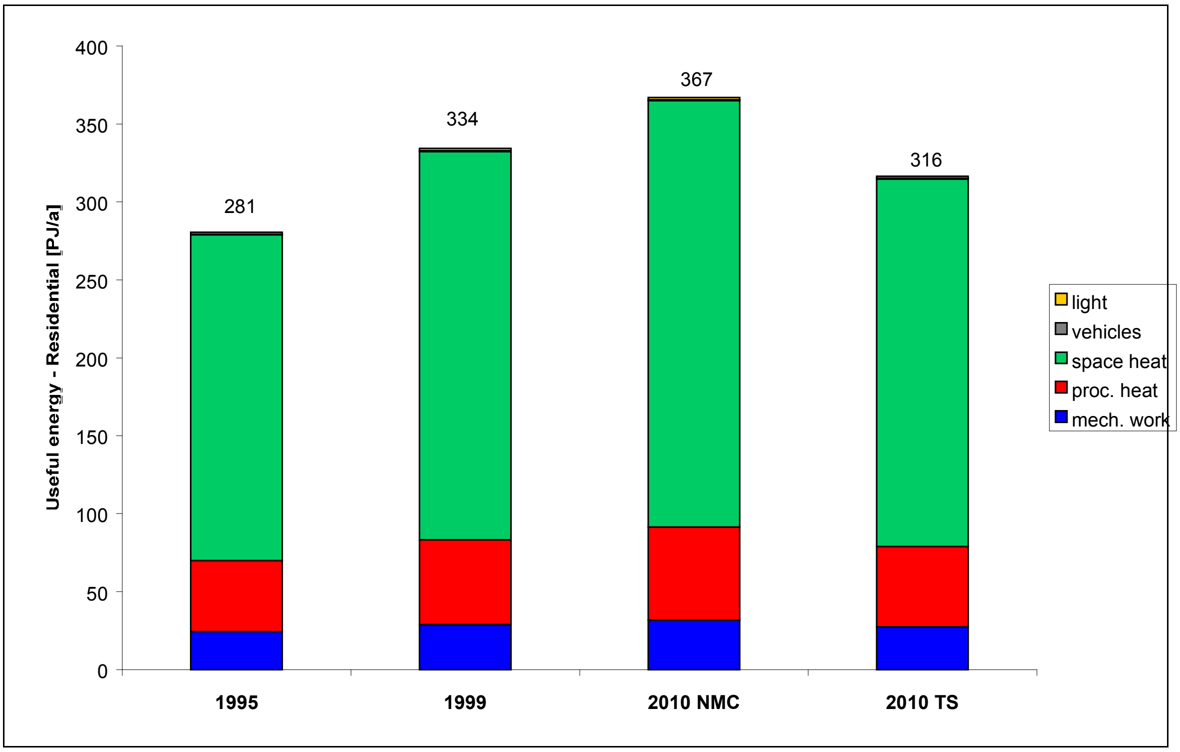


Figure A 3-13: Results of dynamic behavior of the need of useful energy in the residential sector



Final energy

The demand of useful energy determines the need of final energy carrier. The need of final energy is in scenario NMC (1000 PJ/a) about 200 PJ higher that in scenario TS (900 PJ/a) in year 2010 (Figure A 3-14). This difference is mainly caused by a strong decrease of oil for transportation and space heat. The share of coal is decreasing in both scenarios, the share of gas and electricity is decreasing in scenario TS and the share of biomass and heat is increasing in both scenarios, as a representative example the mix for space heat in the residential sector is shown in Figure A 3-15.

Figure A 3-14: Results of dynamic behavior of the need of final energy in the end use categories

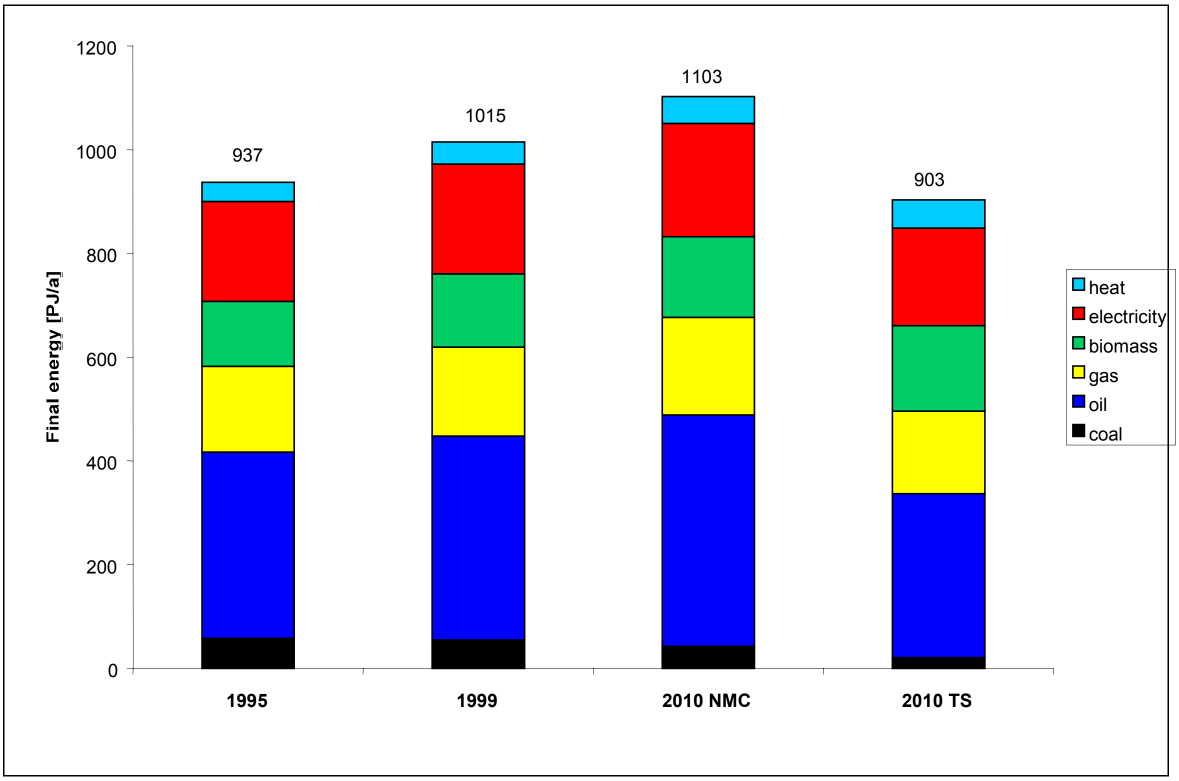
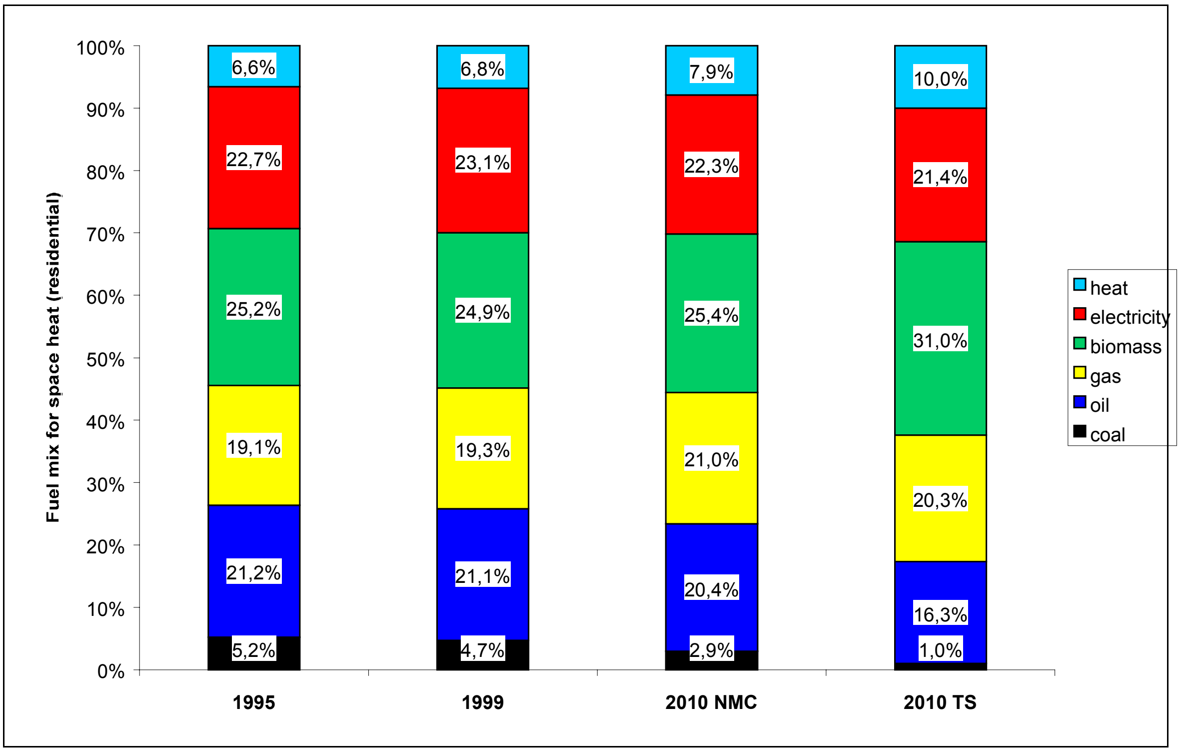


Figure A 3-15: Results of dynamic behavior of fuel mix for space heat in the residential sector



Primary energy

The need of final energy determines the need of primary energy, which is in year 2010 for scenario TS (1,460 PJ/a) about 210 PJ lower than in scenario NMC (1,250 PJ/a). The share of coal is decreasing in both scenarios, share of oil is decreasing in scenario TS, share of gas is increasing in scenario TS and share of biomass is increasing in both scenarios (Figure A 3-16).

Figure A 3-16: Results of dynamic behavior of the need of primary energy in the two scenarios

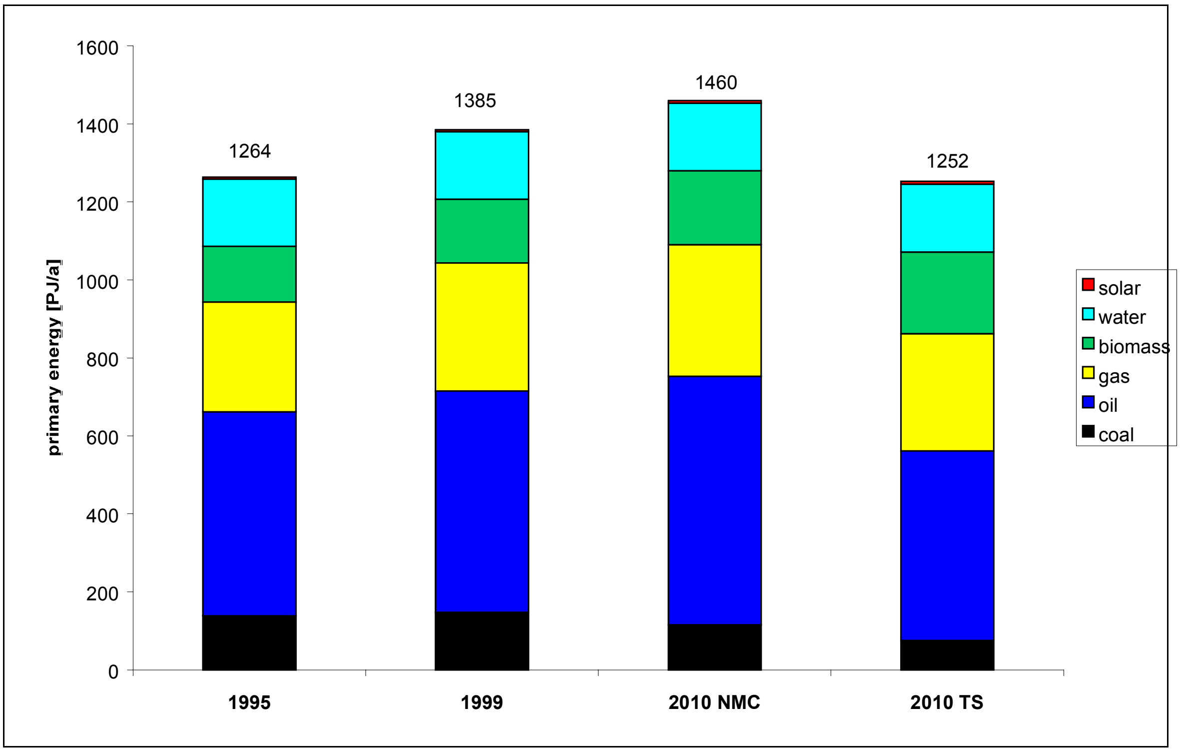
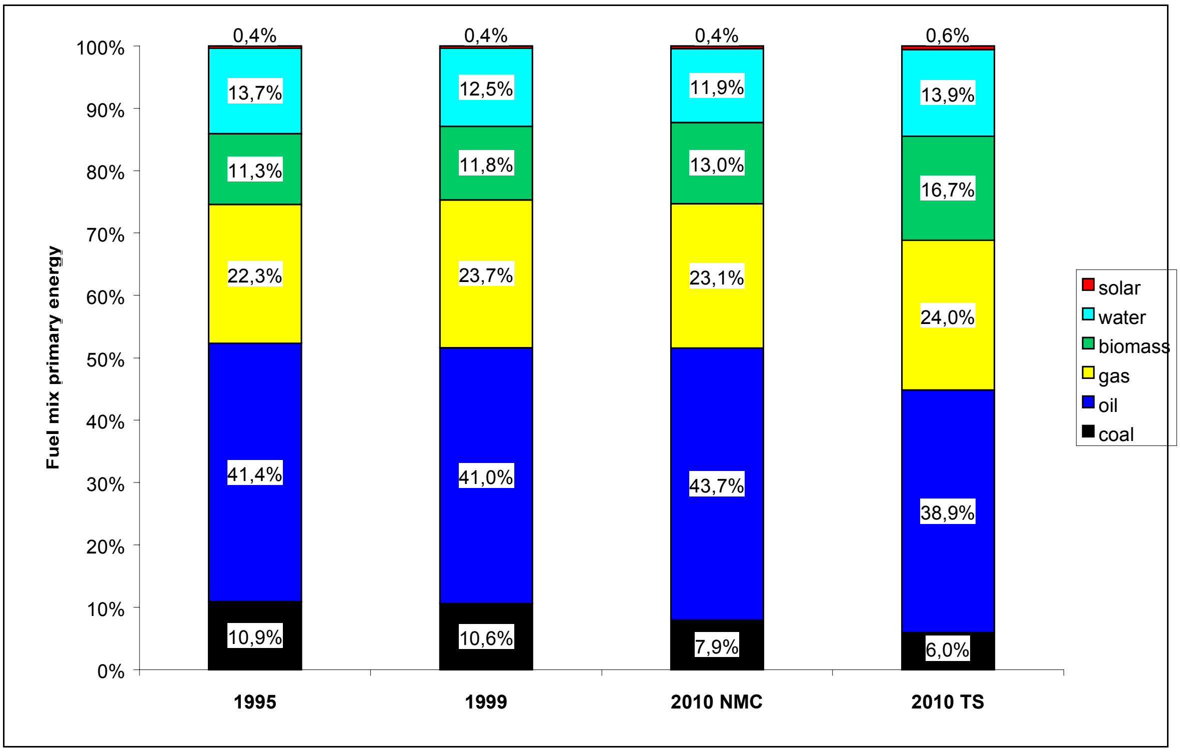


Figure A 3-17: Results of dynamic behavior of primary energy fuel mix



A 3-3.2 Scenario: No major changes

The results of scenario NMC are analyzed by showing the development of carbon flows to {ATMO} and the description of the major carbon flows.

Development of carbon flows to {ATMO}

In Figure A 3-18 the development of the carbon flows to {ATMO} from 1990 to 2010 in the scenario “no major changes” is shown.

The following carbon flows to {ATMO} are increasing, given as a percentage from 2010 referring to 1990 (1990 = 100%):

- ET_mechanical work: 172%, mainly because of increasing energy services in industry sector
- ET_space heat: 117%, mainly because of increasing energy services in residential sector
- ET_vehicles: 157%, mainly because of increasing energy services in transportation sector
- ET_blast furnace, coke plant: 192%, increasing demand of coke for basic material industry
- ET_CHP plant: 225%, increasing demand on electricity and heat
- ET_heating plant:155%, increasing demand on heat

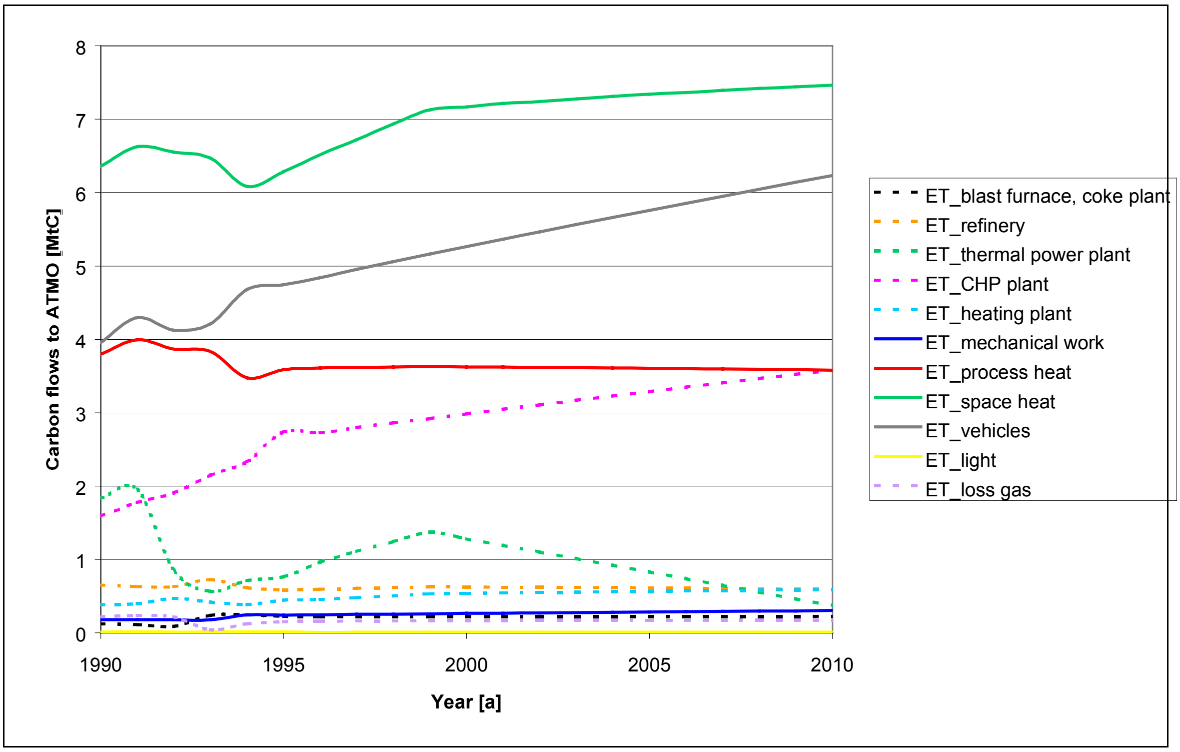
The following carbon flows to {ATMO} are decreasing, given as a percentage from 2010 referring to 1990 (1990 = 100%):

- ET_process heat: 94%, mainly because of improved productivity
- ET_loss gas: 81%, mainly because of more efficient gas distribution systems

- ET_refinery: 91%, mainly because of improved transformation efficiency
- ET_thermal power plant: 20%, mainly because of increased electricity production in CHP plants

In total the carbon flows from {ENERGY} to {ATMO} increase from 19,1 MtC in 1990 to 23,13 MtC in 2010, that are 121% of 1990.

Figure A 3-18: Development of carbon flows to {ATMO} from 1990 to 2010 in scenario “no major changes”



The carbon in the flows of primary energy shows an increase in

- E_oil: 132%, mainly because of increasing oil demand for vehicles and space heat
- E_gas: 144%, mainly because of increasing gas demand for process and space heat and CHP plants
- E_biomass: 132%, mainly because of increasing biomass demand for process and space heat, CHP and heating plants

and a decrease in

- E_coal: 65%, mainly because of decreasing coal demand for process and space heat.

In total the carbon flows in primary energy to {ENERGY} increase from 22.05 MtC in 1990 to 26.56 MtC in 2010, that are 120% of 1990.

Major carbon flows

All carbon flows in {ENERGY} that come from another module or go to an other module and that are > 1 MtC/a, are defined as “major carbon” flows. These flows are shown in Figure A 3-19, by giving the absolute amount in 1990 and 2010 for the scenario “no major changes”:

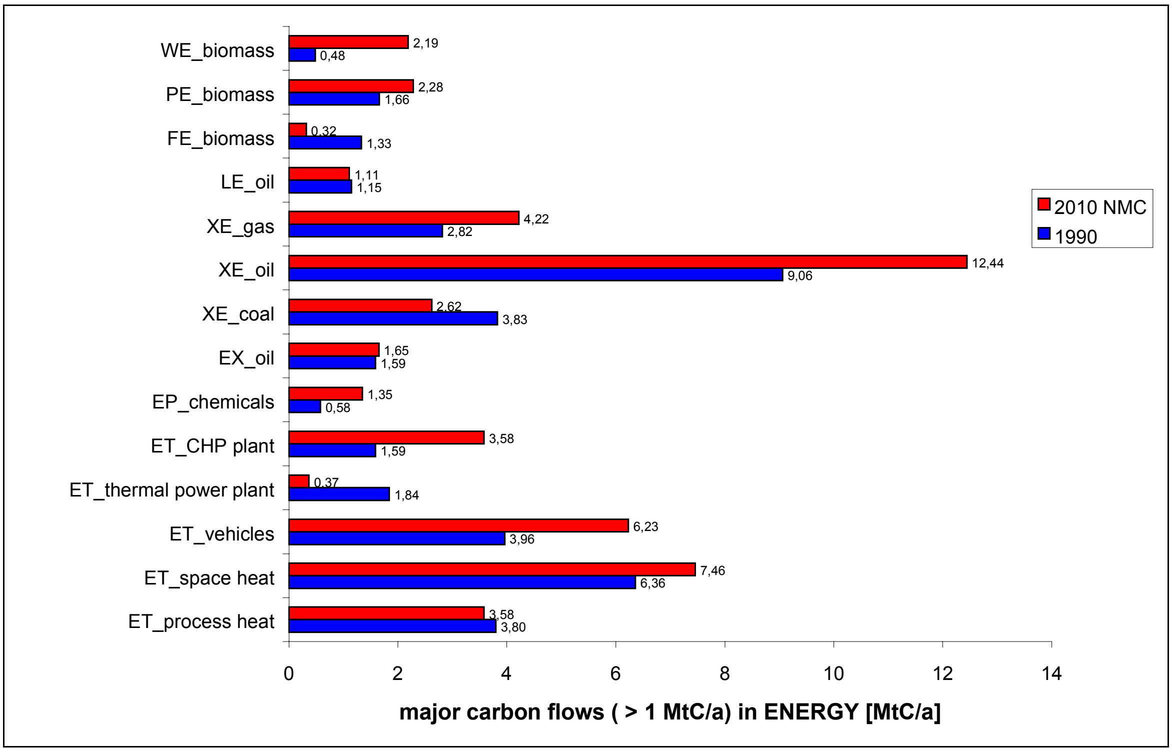
The following major flows are increasing, given as a percentage from 2010 referring to 1990 (1990 = 100%):

- WE_biomass: 456%, mainly because of increasing thermal waste treatment
- PE_biomass: 137%, mainly because of increased production in wood industry
- XE_gas: 150%, mainly because of increasing use of gas for CHP plants, process and space heat
- XE_oil: 137%, mainly because of increased oil demand for vehicles and space heat
- EX_oil: 104%, mainly because of globalisation with increasing import/export
- EP_chemicals: 233%, mainly because of increased plastic production
- ET_CHP plant: 225%, increasing demand on electricity and heat
- ET_vehicles: 157%, mainly because of increasing energy services in transportation sector
- ET_space heat: 117%, mainly because of increasing energy services in residential sector

The following major flows are decreasing, given as a percentage from 2010 referring to 1990 (1990 = 100%):

- FE_biomass: 24%, mainly because of increasing biomass from {WASTE} and {PROD}
- LE_oil: 97%, mainly because of less domestic exploitation
- XE_coal: 68%, mainly because of less coal demand for space and process heat
- ET_thermal power plant: 20%, mainly because of increased electricity production in CHP plants
- ET_process heat: 94%, mainly because of improved productivity

Figure A 3-19: Major carbon flows in {ENERGY} in scenario “no major changes”



Interaction with other modules

In Figure A 3-20 and Figure A 3-21 the interactions with the other modules are shown, this means the development of carbon flows to and from {ENERGY}, whereas the changes of the carbon flows between the modules are compared to 1990. Figure A 3-22 gives the balance of the net flows of {ENERGY}, whereas values > 0 refer to net flows out of {ENERGY} and values > 0 to net flows to {ENERGY}. Most of the relevant explanations of parts of these figures are given in the prevoius chapters.

It can be seen that the change of total carbon flow is dominated by the flow to {ATMO}, that is increasing, which reflects the higher need of carbon related energy carrier to satisfy the increasing demand of energy services. The flow to {PROD} has a steady increase, because of increasing need of raw materials for production. The flows to {IMP/EXP} and {WASTE} are nearly constant.

The carbon flows to {ENERGY} are dominated by the flow from {IMP/EXP}, because of the import of fossil fuels. The flow from {IMP(EXP} is increasing, because of the increasing energy demand, that is mainly satisfied with imported oil and gas. The flow from {WASTE} is increasing, because of increased combustion of waste instead of landfill. The flow from {PROD} is increasing, because of increased production of wood products. The flow from {AGRO} and {LITHO} are constant. The flow from {FOREST} is decreasing, because the biomass need of {ENERGY} is satisfied with the increasing biomass supply from {PROD} and {WASTE}.

Figure A 3-20: Flows from {ENERGY} to other modules compared to 1990 in scenario “no major changes”

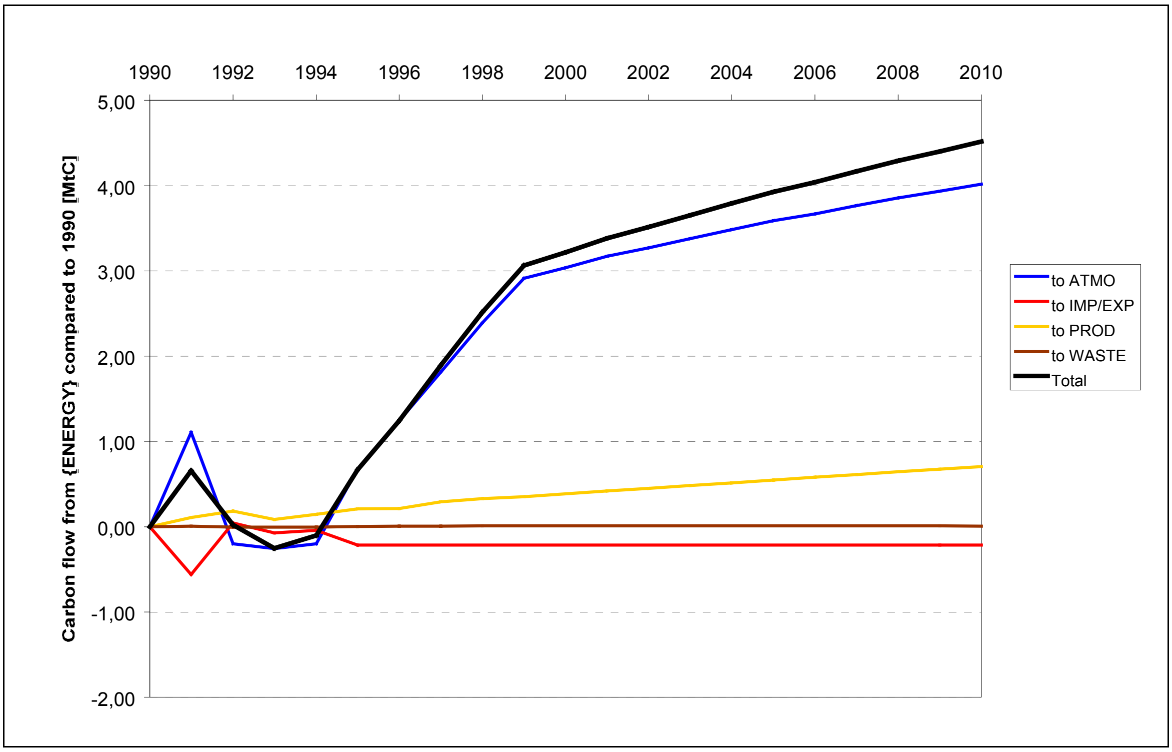


Figure A 3-21: Flows from other modules to {ENERGY} compared to 1990 in scenario “no major changes”

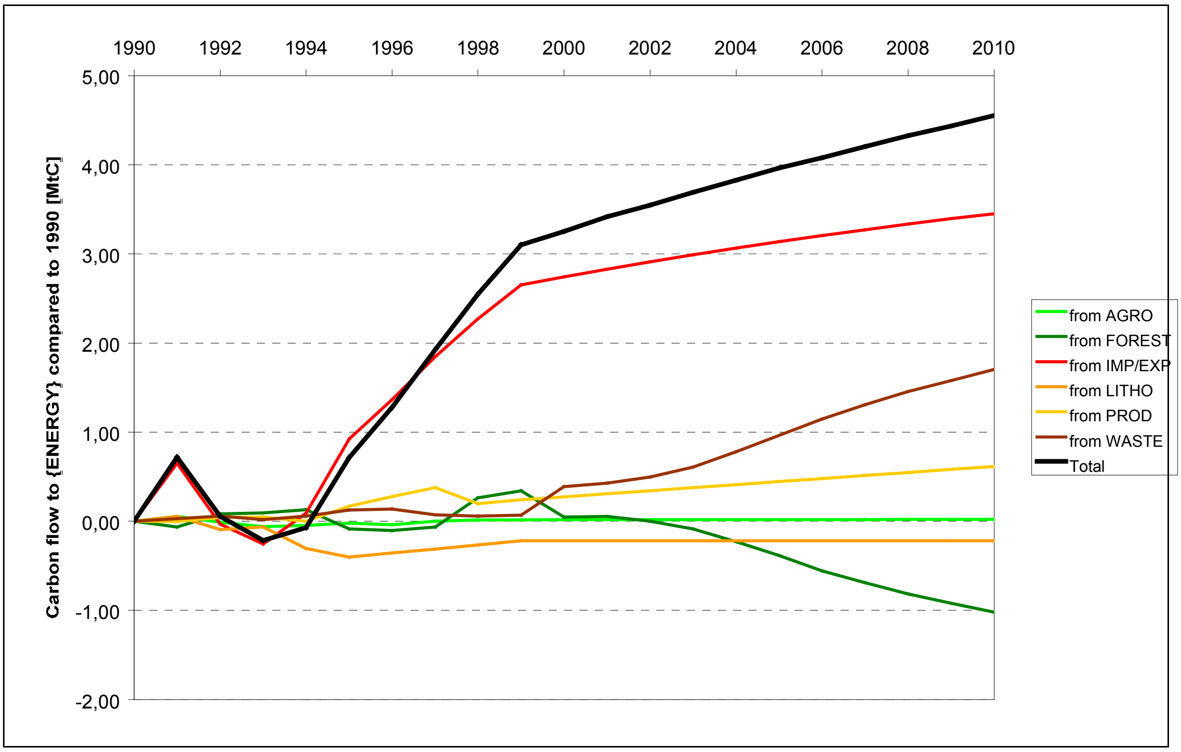
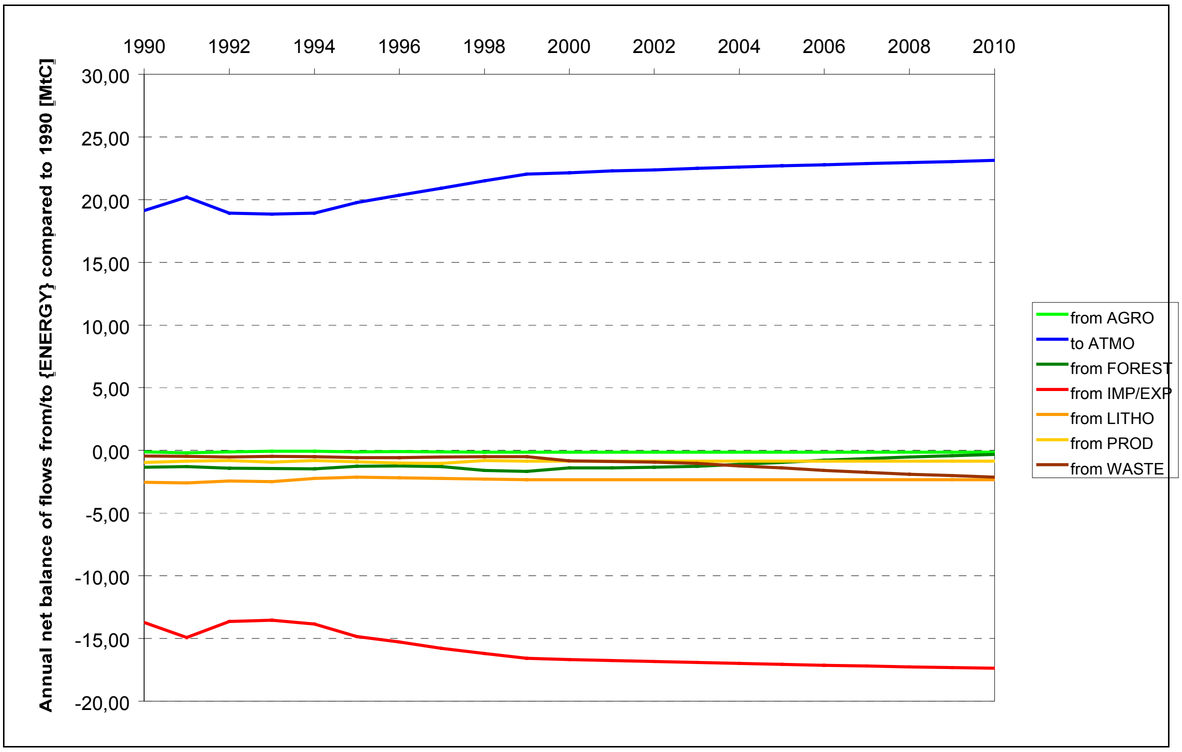


Figure A 3-22: Annual net balance of flows from/to other modules to/from {ENERGY} compared to 1990 in scenario “no major changes”



Conclusions

The results of the scenario NMC demonstrate, that according to the high increase of energy demand the carbon flows to the atmosphere are increasing. This additional energy need will mainly be satisfied with oil and gas and only for a small fraction with renewable especially with biomass, while the use of coal will decrease. The highest increases derive from vehicles in transportation sector and space heat in residential sector, because of the huge growing number of vehicles and floor space.

A 3-3.3 Scenario: Towards sustainability

The results of scenario TS are analyzed by showing the development of carbon flows to {ATMO} and the description of the major carbon flows.

Development of carbon flows to {ATMO}

In Figure A 3-23 the development of the important carbon flows from 1990 to 2010 in the scenario “toward sustainability” is shown. The following carbon flows to {ATMO} are increasing, given as a percentage from 2010 referring to 1990 (1990 = 100%):

- ET_mechanical work: 128%, mainly because of increasing energy services in industry sector
- ET_vehicles: 116%, mainly because of increasing energy services in transportation sector
- ET_blast furnace, coke plant: 175%, increasing demand of coke for basic material industry

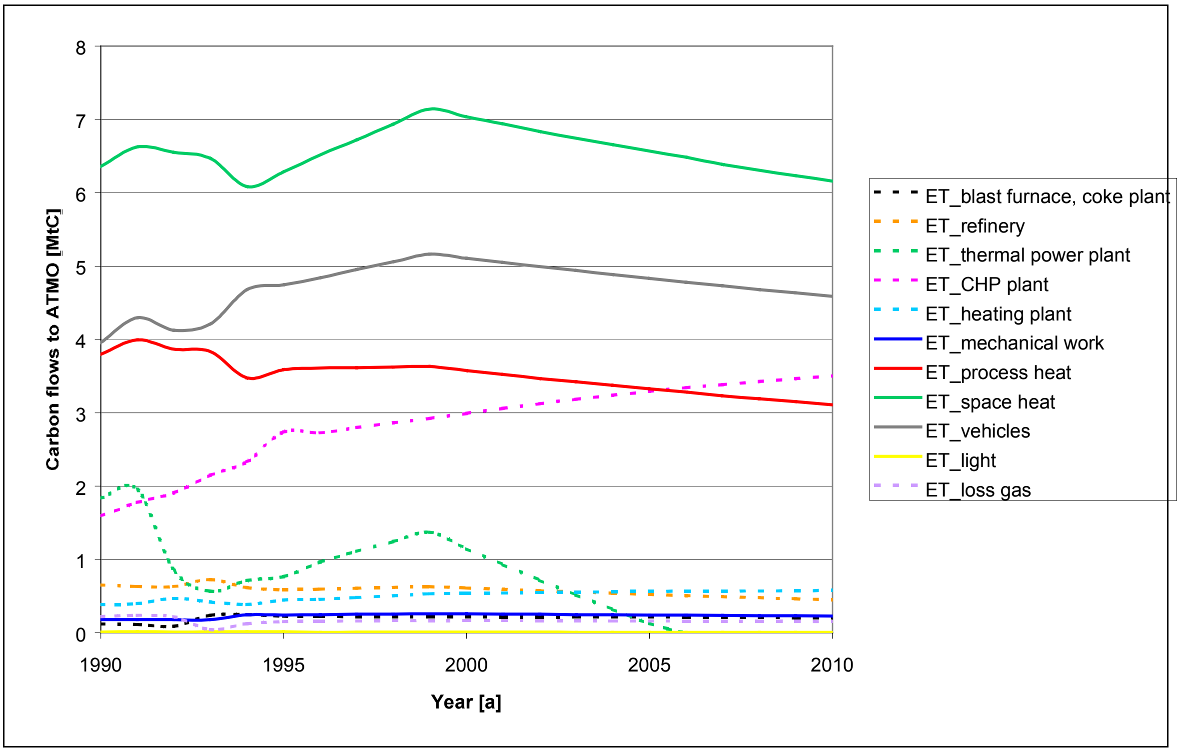
- ET_CHP plant: 220%, increasing demand on electricity and heat
- ET_heating plant:152%, increasing demand on heat

The following carbon flows to {ATMO} are decreasing, given as a percentage from 2010 to 1990 (1990 = 100%):

- ET_process heat: 82%, mainly because of improved productivity
- ET_space heat: 97%, mainly because of improved productivity in residential sector
- ET_loss gas: 68%, mainly because of more efficient gas distribution systems
- ET_refinery: 69%, mainly because of improved transformation efficiency
- ET_thermal power plant: 0%, mainly because of increased electricity production in CHP plants

In total the carbon flows from {ENERGY} to {ATMO} has a slight decrease from 19,1 MtC in 1990 to 18,9 MtC in 2010, that are 99% of 1990.

Figure A 3-23: Development of carbon flows to {ATMO} from 1990 to 2010 in scenario “towards sustainability”



The carbon in the flows of primary energy show an increase in

- E_oil: 101%, mainly because of constant oil demand
- E_gas: 129%, mainly because of increasing gas demand for process and space heat and CHP plants
- E_biomass: 147%, mainly because of increasing biomass demand for process and space heat, CHP and heating plants

and a decrease in

- E_coal: 43%, mainly because of decreasing coal demand for process and space heat.

In total the carbon flows in primary energy to {ENERGY} has a slight increase from 22.05 MtC in 1990 to 22.34 MtC in 2010, that are 101% of 1990.

Major carbon flows

All carbon flows in {ENERGY} that come from another module or go to an other module and that are > 1 MtC/a, are defined as “major carbon” flows. These flows are shown in Figure A 3-24, by giving the absolute amount in 1990 and 2010 for the scenario “towards sustainability”:

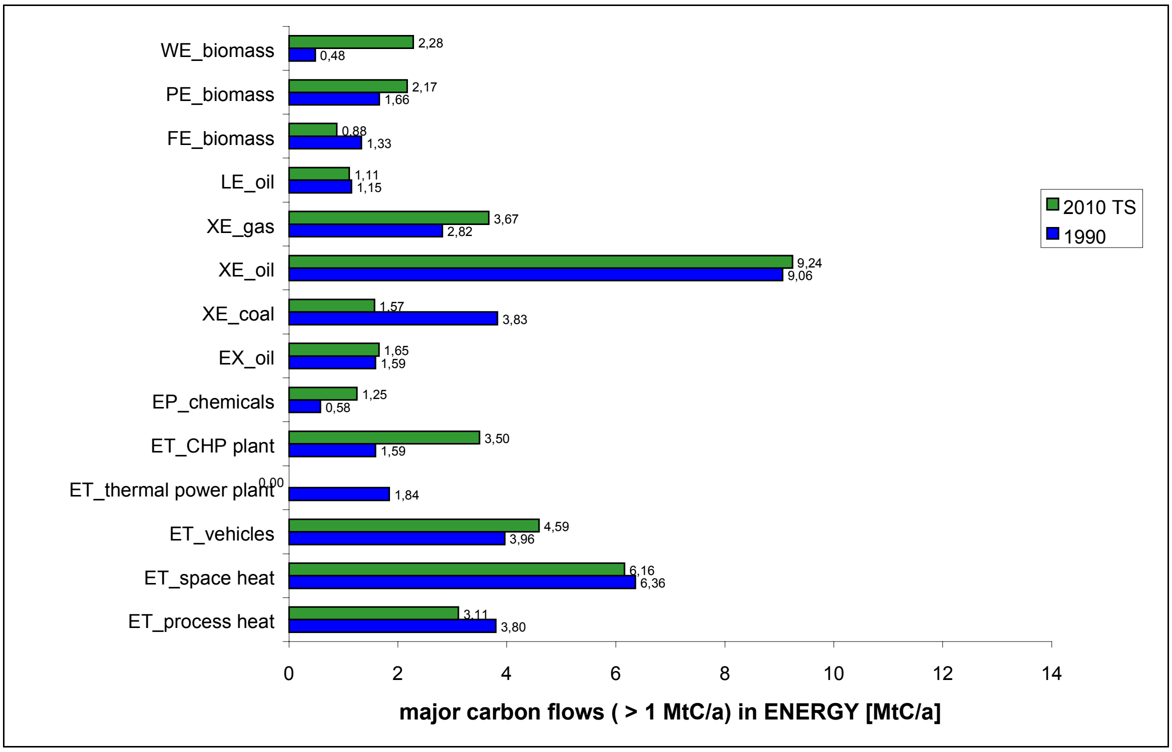
The following major flows are increasing, given as a percentage from 2010 referring to 1990 (1990 = 100%):

- WE_biomass: 475%, mainly because of increasing thermal waste treatment
- PE_biomass: 131%, mainly because of increased production in wood industry
- XE_gas: 130%, mainly because of increasing use of gas for CHP plants, process and space heat
- XE_oil: 137%, mainly because of increased oil demand for vehicles and space heat
- EX_oil: 104%, mainly because globalization with increasing import/export
- EP_chemicals: 216%, mainly because of increased plastic production
- ET_CHP plant: 220%, increasing demand on electricity and heat
- ET_vehicles: 116%, mainly because of increasing energy services in transportation sector

The following major flows are decreasing, given as a percentage from 2010 referring to 1990 (1990 = 100%):

- FE_biomass: 66%, mainly because of increasing biomass from {WASTE} and {PROD}
- LE_oil: 97%, mainly because of less domestic exploitation
- XE_coal: 41%, mainly because of less coal demand for space and process heat
- ET_thermal power plant: 0%, mainly because of increased electricity production in CHP plants
- ET_space heat: 97%, mainly because of improved productivity
- ET_process heat: 82%, mainly because of improved productivity

Figure A 3-24: Major carbon flows in {ENERGY} in scenario “towards sustainability”



Interaction with other modules

In Figure A 3-25 and Figure A 3-26 the interactions with the other modules are shown, this means the development of carbon flows to and from {ENERGY}, whereas the changes of the carbon flows between the modules are compared to 1990. Figure A 3-27 gives the net flows of the {ENERGY} module, whereas values > 0 refer to net flows out of {ENERGY} and values > 0 to net flows to {ENERGY}. Most of the relevant explanations of parts of these figures are given in the prevoius chapters.

It can be seen that the change of total carbon flow is dominated by the flow to {ATMO}, which reflects the higher need of carbon related energy carrier. The total flow is increasing from 1990 to 2000 and then it is decreasing, but it does not reach the size of 1990 in 2010. The flow to {PROD} has a steady increase, because of increasing need of raw materials. The flows to {IMP/EXP} and {WASTE} are nearly constant.

The carbon flows to {ENERGY} are dominated by the flow from {IMP/EXP}, because of the import of fossil fuels. The flow from {IMP(EXP} starts to decrease in year 2000, because of increasing use of renewable energy carrier mainly instead of imported oil. The flow from {WASTE} is increasing, because of increased combustion of waste instead of landfill. The flow from {PROD} is increasing, because of increased production of wood products. The flow from {AGRO} and {LITHO} are constant. The flow from {FOREST} is decreasing, because of the biomass need of {ENERGY} is satisfied with the increasing biomass supply from {PROD} and {WASTE}.

Figure A 3-25: Flows from {ENERGY} to other modules compared to 1990 in scenario “towards sustainability”

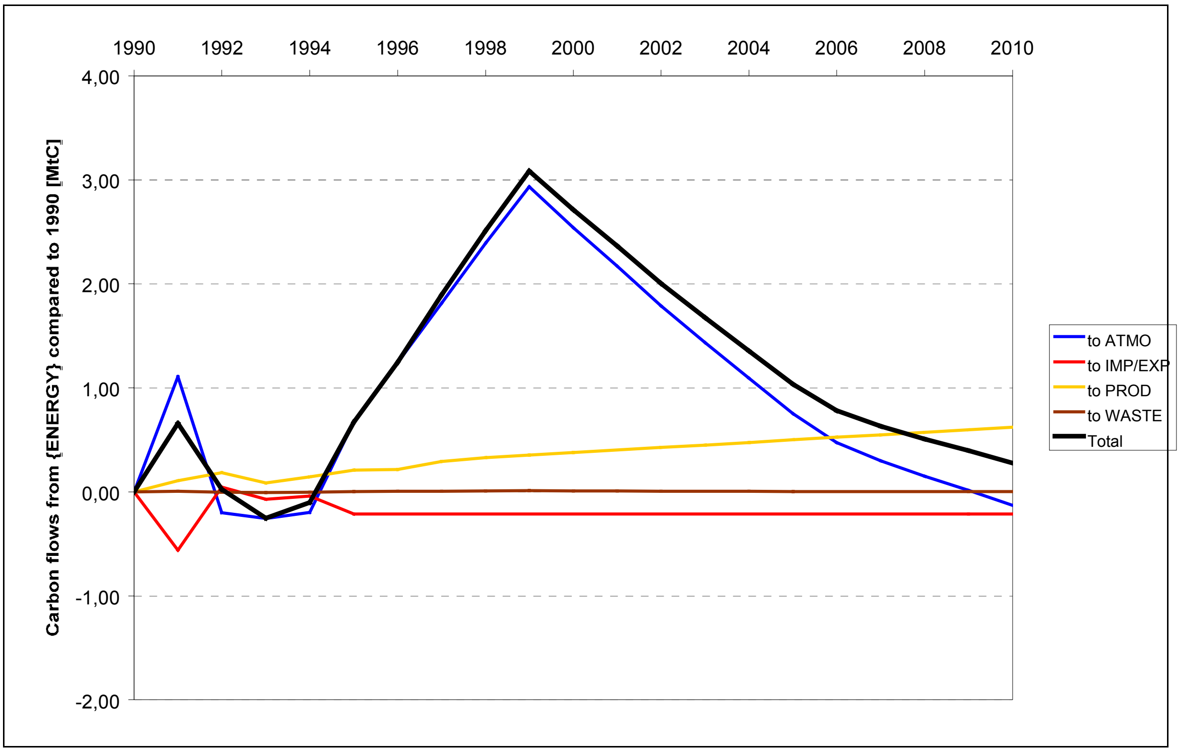


Figure A 3-26: Flows from other modules to {ENERGY} compared to 1990 in scenario “towards sustainability”

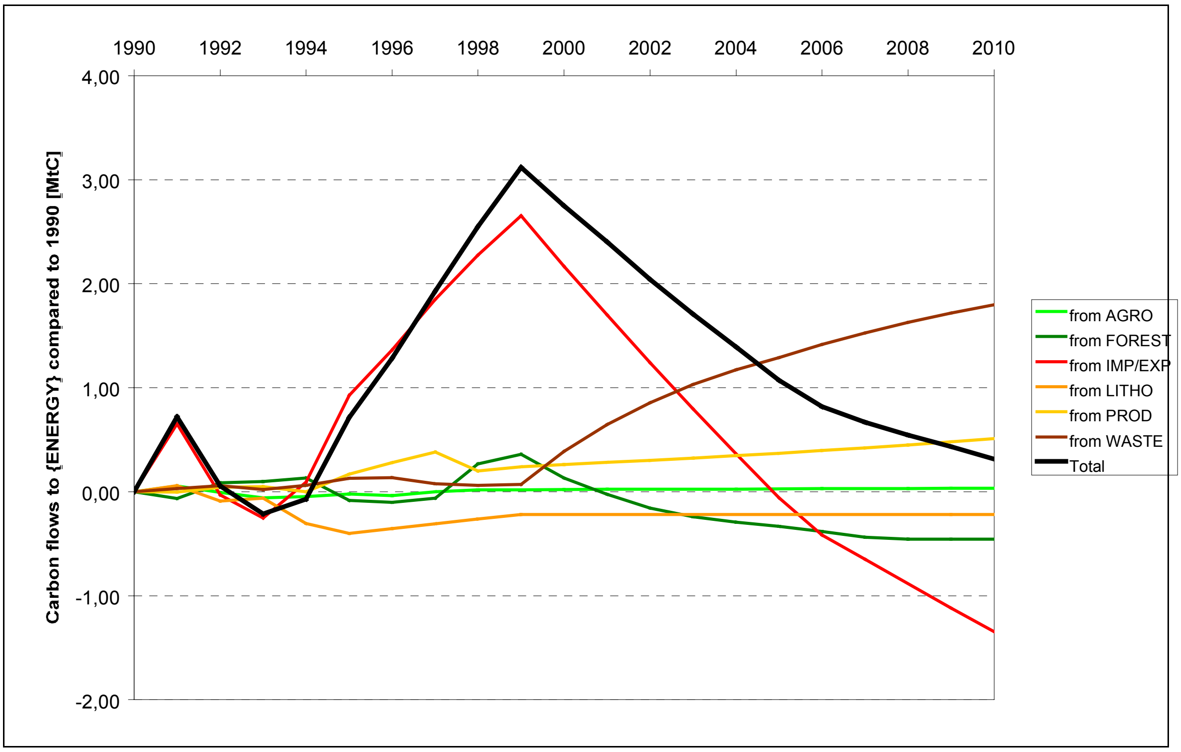
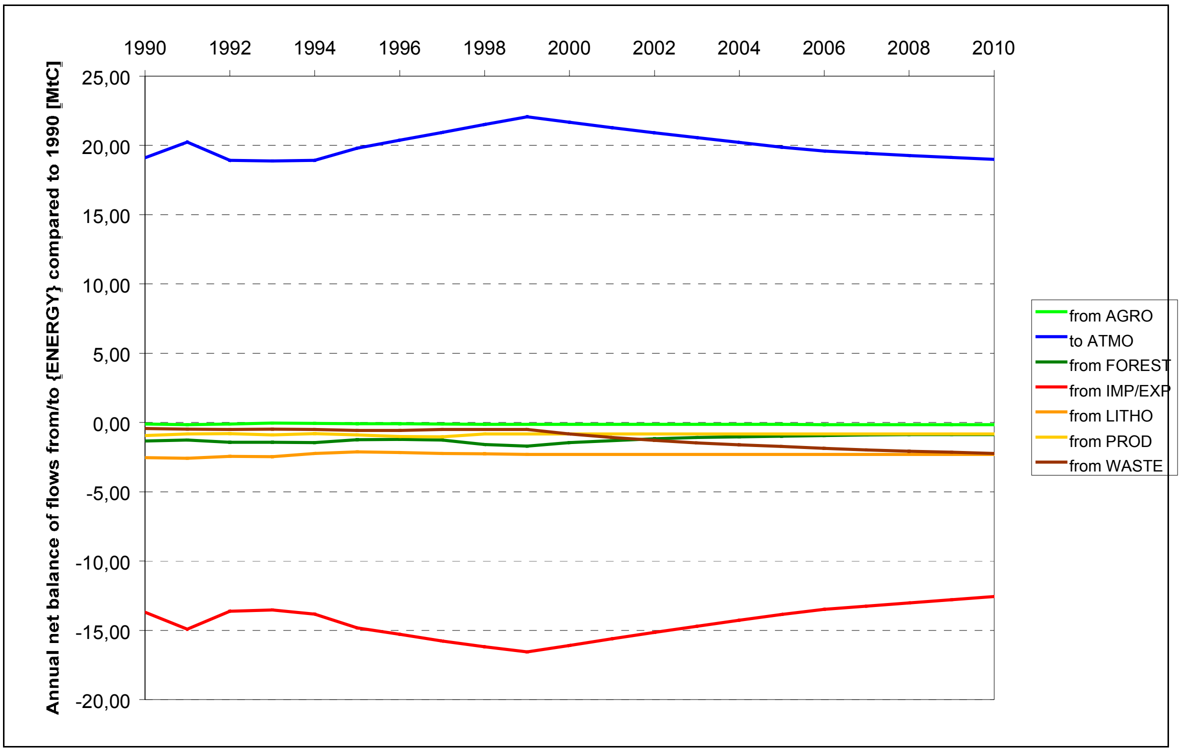


Figure A 3-27: Annual net balance of flows from/to other modules to/from {ENERGY} compared to 1990 in scenario “towards sustainability”



Conclusions

The results of the scenario TS demonstrate, that the demand of useful energy is decreasing even if the demand of energy services is increasing. This leads to a decrease of the carbon flows to the atmosphere. The energy demand will be satisfied with a growing share of gas and renewable especially biomass, a stable use of oil and a strong decrease of coal. But it might be deduced, that an enormous improving of energy productivity and efficiency is necessary especially in the transportation sector with vehicles and in residential sector with space heat, to compensate to the huge growing number of vehicles and of floor space. But the results of the scenario TS show the direction to a sustainable energy system in Austria.

A 3-3.4 Comparison of Scenarios

The comparison of the two scenarios is analyzed by showing the difference of the development of carbon flows to {ATMO} and the difference of major carbon flows.

Difference in development of carbon flows to {ATMO}

In Figure A 3-28 the difference in development of the important carbon flows in year 2010 in the two scenarios is shown. The difference of the following carbon flows to {ATMO} are given as a percentage from the carbon flow in the scenario “no major changes” to the scenario “towards sustainability” in 2010 (scenario “no major changes” = 100%):

- ET_mechanical work: 74%, mainly because of higher productivity and lower increasing of energy services in industry sector

- ET_process heat: 87%, mainly because of higher productivity and lower increasing of energy services in industry sector
- ET_space heat: 83%, mainly because of higher productivity and lower increasing of energy services in residential sector
- ET_vehicles: 74%, mainly because of higher productivity and lower increasing of energy services in transportation sector
- ET_blast furnace, coke plant: 91%, mainly because of lower increasing demand of coke
- ET_loss gas: 83%, mainly because of lower demand of gas
- ET_refinery: 91%, mainly because of lower demand of oil
- ET_thermal power plant: 0%, mainly because all thermal electricity is produced in CHP plants
- ET_CHP plant: 98%, mainly because of lower increase of electricity and heat demand
- ET_heating plant:98%, mainly because of lower increase of heat demand

In total the carbon flows from {ENERGY} to {ATMO} in 2010 is in scenario “no major changes” 23,1 MtC and in scenario “towards sustainability” 18,9 MtC, that are 82%.

Figure A 3-28: Difference of development of carbon flows to {ATMO} from 1990 to 2010 in scenario “no major changes” and “towards sustainability

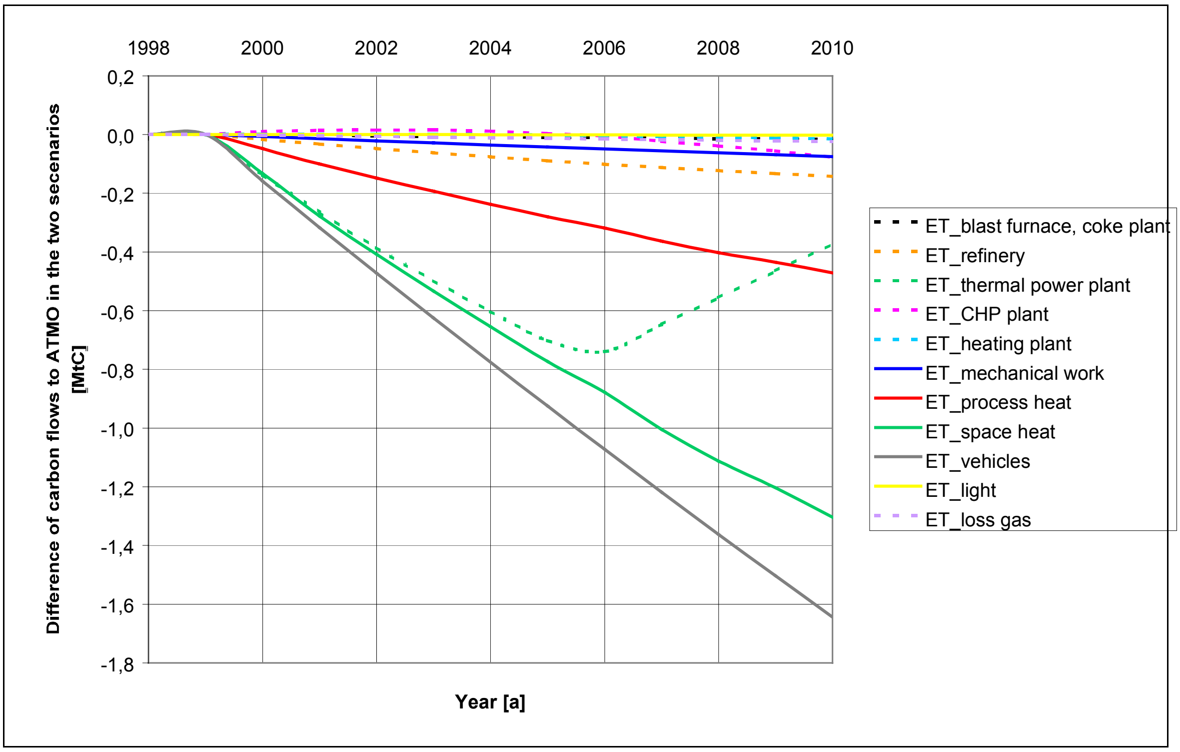
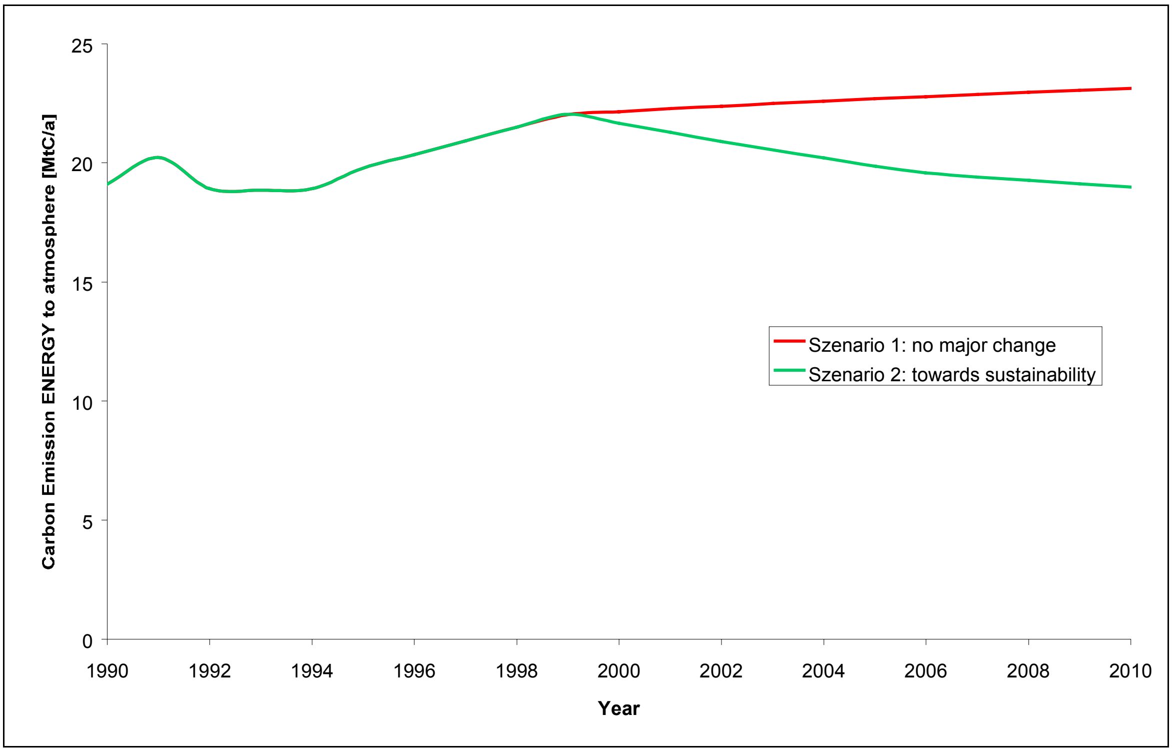


Figure A 3-29: Difference of carbon flows to {ATMO} from 1990 to 2010 in scenario “no major changes” and “towards sustainability



The difference in the carbon flows of primary energy between the two scenarios shows

- E_coal: 65%, mainly because of stronger decreasing coal demand for process and space heat.
- E_oil: 76%, mainly because of slower increasing oil demand for vehicles
- E_gas: 89%, mainly because of slower increasing gas demand for process and space heat
- E_biomass: 111%, mainly because of higher increasing biomass demand for process and space heat and CHP plants

In total the carbon flows in primary energy to {ENERGY} in 2010 is in scenario “no major changes” 26.56 MtC and in scenario “towards sustainability” 22.34 MtC, that are 84% (Figure A 3-29).

Difference in major carbon flows

All carbon flows in {ENERGY} that come from another module or go to an other module and that are > 1 MtC/a, are defined as “major carbon” flows. The differences of these flows in the two scenarios are shown in Figure A 3-30, by giving the absolute amount in 2010 for both scenarios. The difference of the following carbon flows are given as a percentage from the carbon flow in the scenario “no major changes” to the scenario “towards sustainability” in 2010 (scenario “no major changes” = 100%):

The following major carbon flows have no difference in the two scenarios:

- LE_oil: 100%, no difference
- EX_oil: 100%, no difference

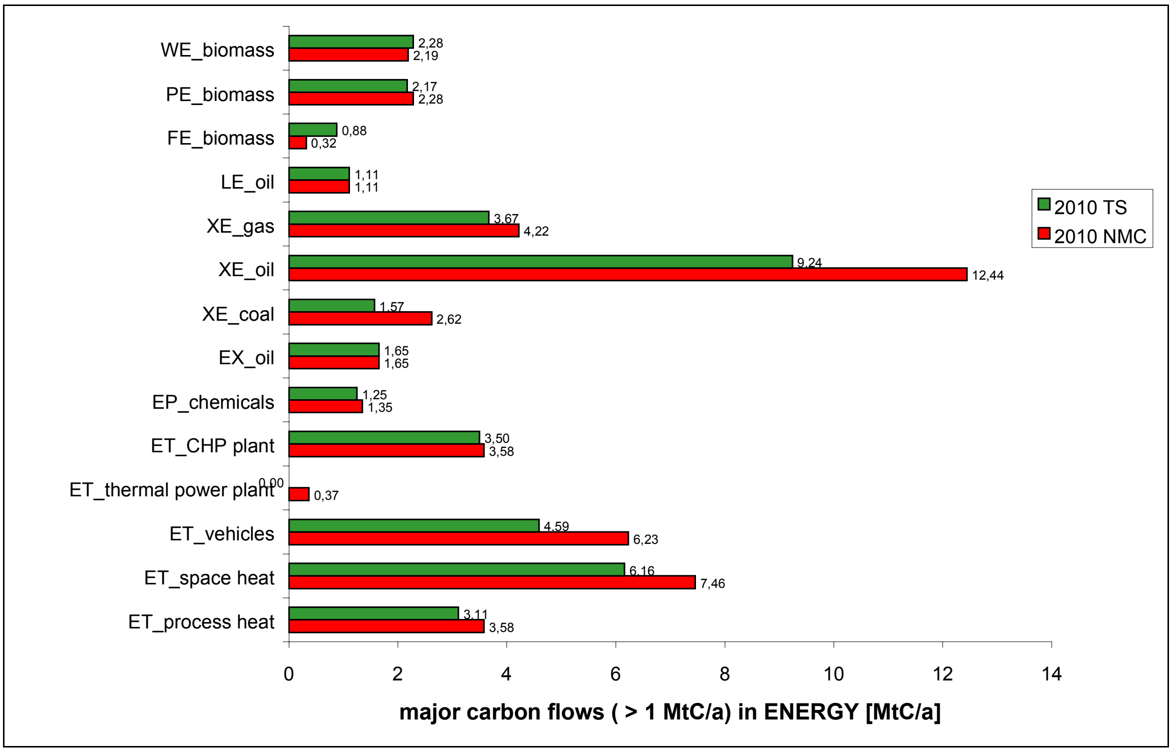
The following major flows are increasing, given as a percentage from scenario TS referring to scenario NMC (NMC = 100%):

- WE_biomass: 104%, mainly because of stronger increase of thermal waste treatment
- FE_biomass: 275%, mainly because of stronger increasing biomass demand for space and process heat

The following major flows are decreasing, given as a percentage from scenario TS referring to scenario NMC (NMC = 100%):

- PE_biomass: 95%, mainly because of lower increase of production in wood industry
- XE_gas: 87%, mainly because of lower increasing gas demand for space and process heat
- XE_oil: 74%, mainly because of lower oil demand for vehicles and space heat
- XE_coal: 60%, mainly because of stronger decreasing coal demand for space and process heat
- EP_chemicals: 93%, mainly because of lower increase of plastic production
- ET_CHP plant: 98%, mainly because of lower electricity demand
- ET_thermal power plant: 0%, mainly because of increased electricity production in CHP plants
- ET_vehicles: 74%, mainly because of lower increase of energy services in transportation sector and stronger increasing of productivity
- ET_space heat: 83%, mainly because of improved productivity
- ET_process heat: 87%, mainly because of improved productivity

Figure A 3-30: Difference in major carbon flows in {ENERGY} in scenario "no major changes" and "towards sustainability"



Difference of Interaction with other modules

In Figure A 3-31 and Figure A 3-32 the differences of the interactions with the other modules in the two scenarios are shown. Figure A 3-33 gives the difference in the two scenarios of the net flows of {ENERGY}. Most of the relevant explanations of parts of these figures are given in the prevoius chapters.

The total carbon flow from energy is lower in the scenario TS. It can be seen that the change of total carbon flow to {ATMO} is very much lower in scenario TS. The change of flow to {PROD} is lower in scenario TS, because of a lower increase of production. The flows to {IMP/EXP} and {WASTE} are nearly the same. The total carbon flow to energy is lower in the scenario TS. The change carbon flows is dominated by the flow from {WASTE} in scenario TS, because of increasing use of waste for energy.

Figure A 3-31: Flows from {ENERGY} to other modules compared to 1990 as difference of both scenarios

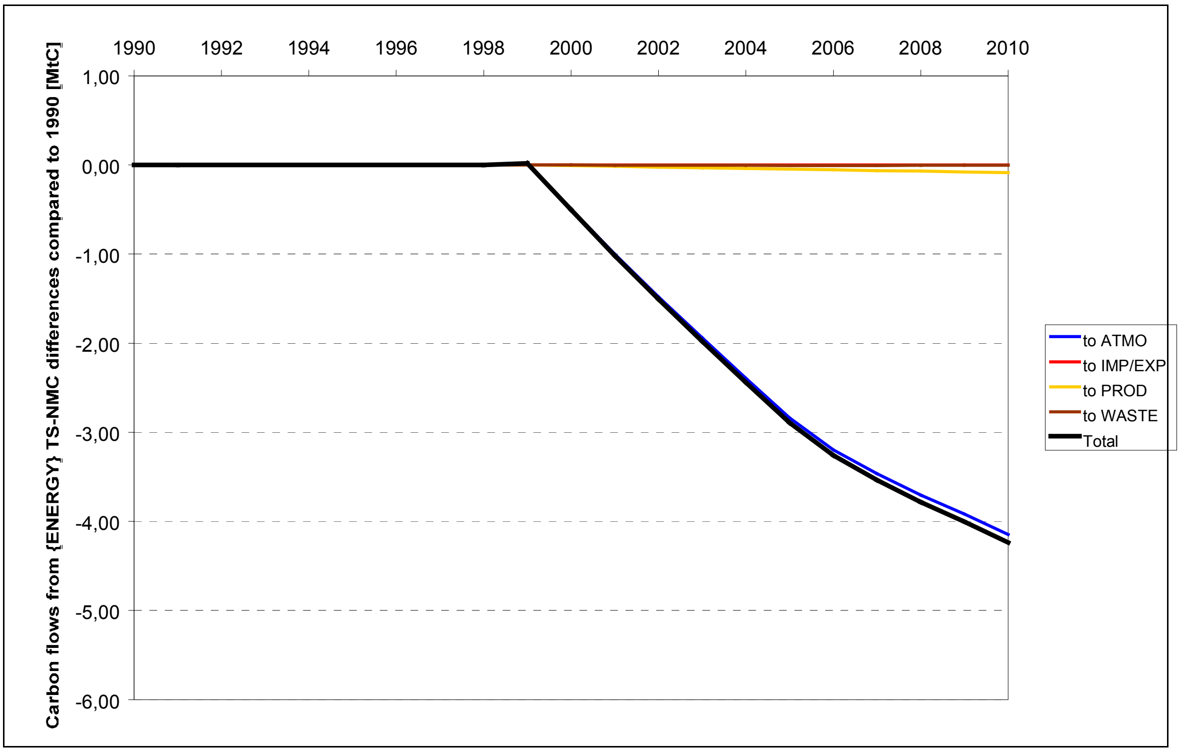


Figure A 3-32: Flows from other modules to {ENERGY} compared to 1990 as difference of both scenarios

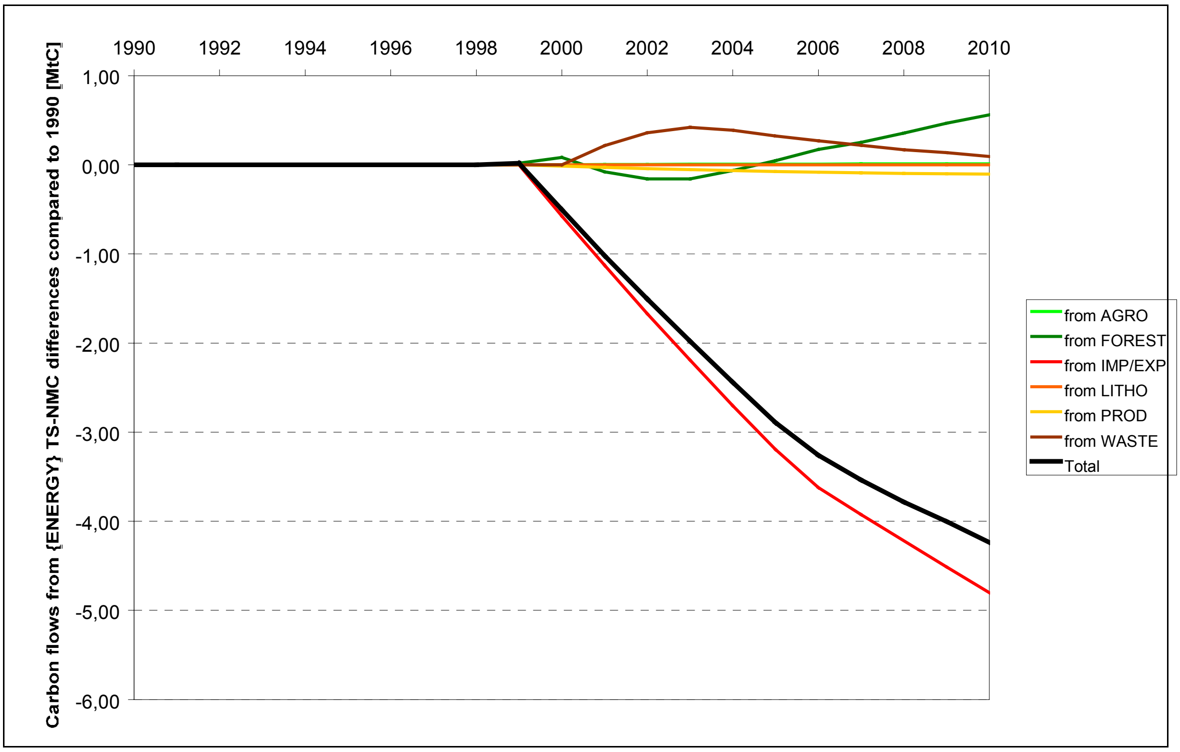
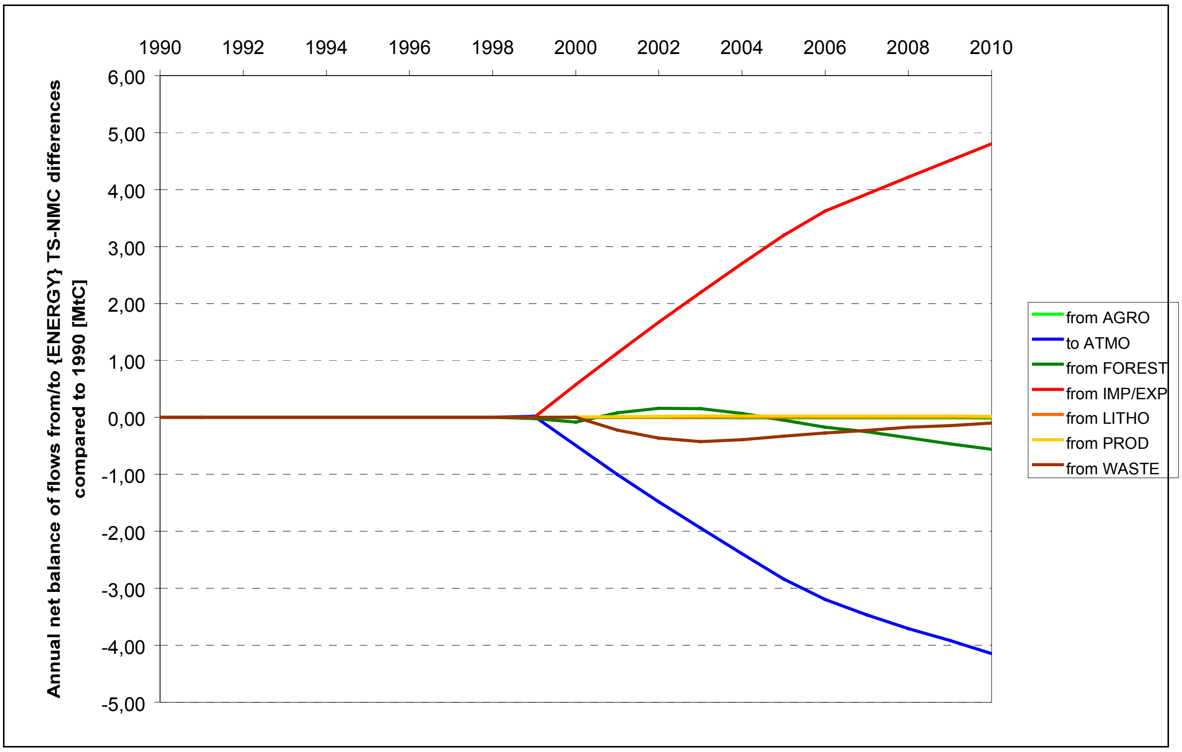


Figure A 3-33: Annual net balance of flows from/to other modules to/from {ENERGY} compared to 1990 as difference of both scenarios



Conclusions

The comparison of the two scenarios demonstrate, that different possible future trends can be modeled in {ENERGY}. The results show that in {ENERGY} a modeling towards a sustainable energy system is possible.

All the carbon flows in {ENERGY} are influenced by human activities. Depending on the activities an increase or an decrease of certain carbon is possible. The most important influences on decreasing of carbon flows are all human activities dealing with energy saving and improving energy efficiency.

A 3-3.5 Sensitivities and Uncertainties

In this chapter the sensitivity and uncertainty analyses are described.

Sensitivity Analysis

The biggest influences result from the assumptions for the driving parameters. Therefore the variation of the driving parameters is done in sensitivity analyses. The most important carbon flow from {ENERGY} is the total carbon flow to {ATMO}. That is why all the following sensitivity analyses are done on the influence on total carbon flow to {ATMO}, which is given for the year 2010 in percent referring to the carbon flow in the scenario “no major changes”.

The sensitivity analyses are divided in 4 parts

1. Variation of productivity, that effects the productivity of mechanical work, process heat, space heat, vehicles, light (sensitivity analyses 1),
2. Variation of development of energy services in industry (production basic material, production electro-chemical industry, production final goods), in residential sector (floor space, production SME) and transportation sector (ton-km and individual-km) (sensitivity analyses 2),
3. Variation of efficiency of energy transformation from final energy to useful energy, that effects the efficiency of transformation for mechanical work, process heat, space heat, vehicles and light (sensitivity analyses 3),
4. Variation of efficiency of energy transformation from primary energy to final energy, that effects blast furnace/coke plant, refinery, hydro plant, thermal power plant, electricity/heat from CHP plant and heating plant (sensitivity analyses 4).

The variation of driving parameters in sensitivity analyses 1 and 2 is chosen as ± 20% of the standard value, in sensitivity analyses 3 and 4 it is ± 5% of the standard value in the scenario “no major changes”, because the possible variation of efficiencies is smaller than the possible variation on parameters for the calculation of useful energy. These 4 sensitivity analyses are shown in Figure A 3-34 to Figure A 3-38. In Figure A 3-36 a detail of the sensitivity analyses 1 and 2 is shown by combining the different productivities and the development of energy services to demonstrate that an increase in energy services needs a stronger increase in productivity for keeping the carbon flow to {ATMO} constant.

The results demonstrate that driving parameters on the demand of useful energy have the biggest influence, the efficiencies of transformation of final energy to useful energy an average influence and the efficiencies of transformation of primary energy to final energy the lowest influence on the change of carbon flow from {ENERGY} to {ATMO}. Because of the big energy need for vehicles, space heat and process heat, the influence of parameters on these three are most important, as shown in Figure A 3-34 and Figure A 3-37.

The result of these sensitivity analyses is the following ranking of the most important driving parameters, that give a significant contribution to change of carbon flow to {ATMO}:

1. productivity space heat (DPE_productivity space heat)
2. productivity vehicles (DPE_productivity vehicles)
3. production SME (DPE_production SME)
4. productivity process heat (DPE_productivity process heat)
5. individual km (DPE_ton-km)
6. ton km (DPE_individual-km)

These parameters are used for the sensitivity analyses of the ACBM model (details see report chapter 3.5.1).

Figure A 3-34: Sensitivity analyses 1 - variation of productivity of useful energy

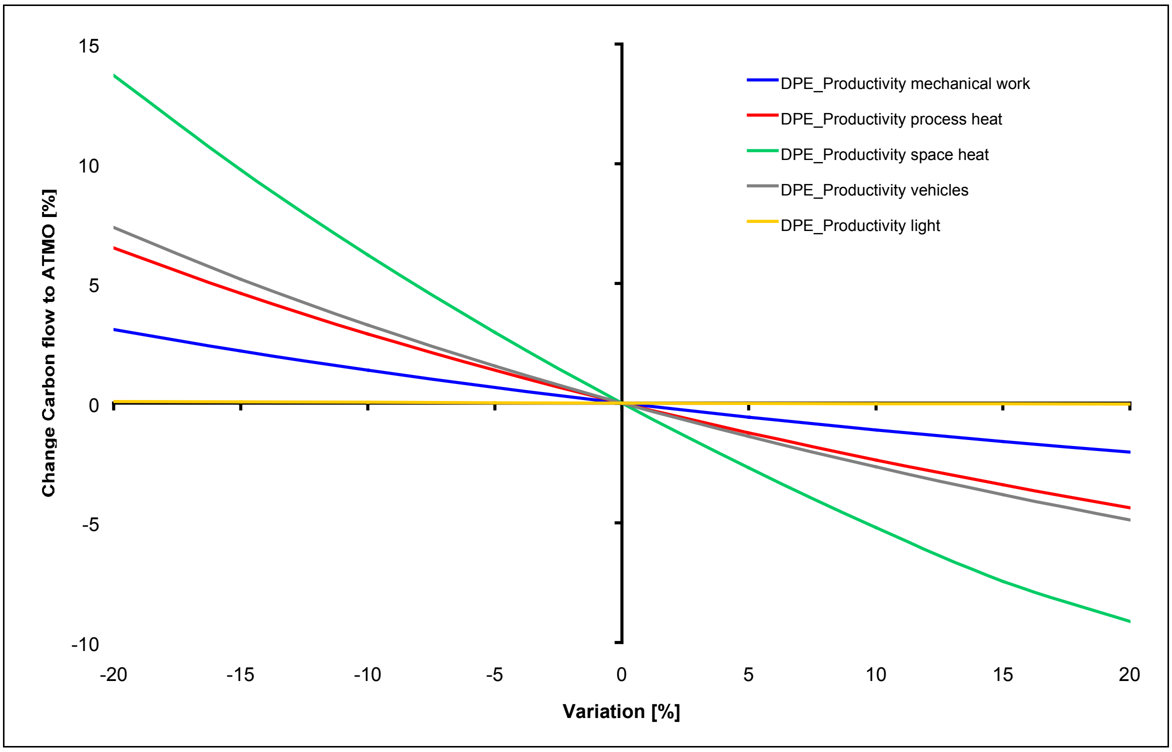


Figure A 3-35: Sensitivity analyses 2 - variation of development of energy services (line of ton km and individual km lie in a pile, therefore only ton km is well seen)

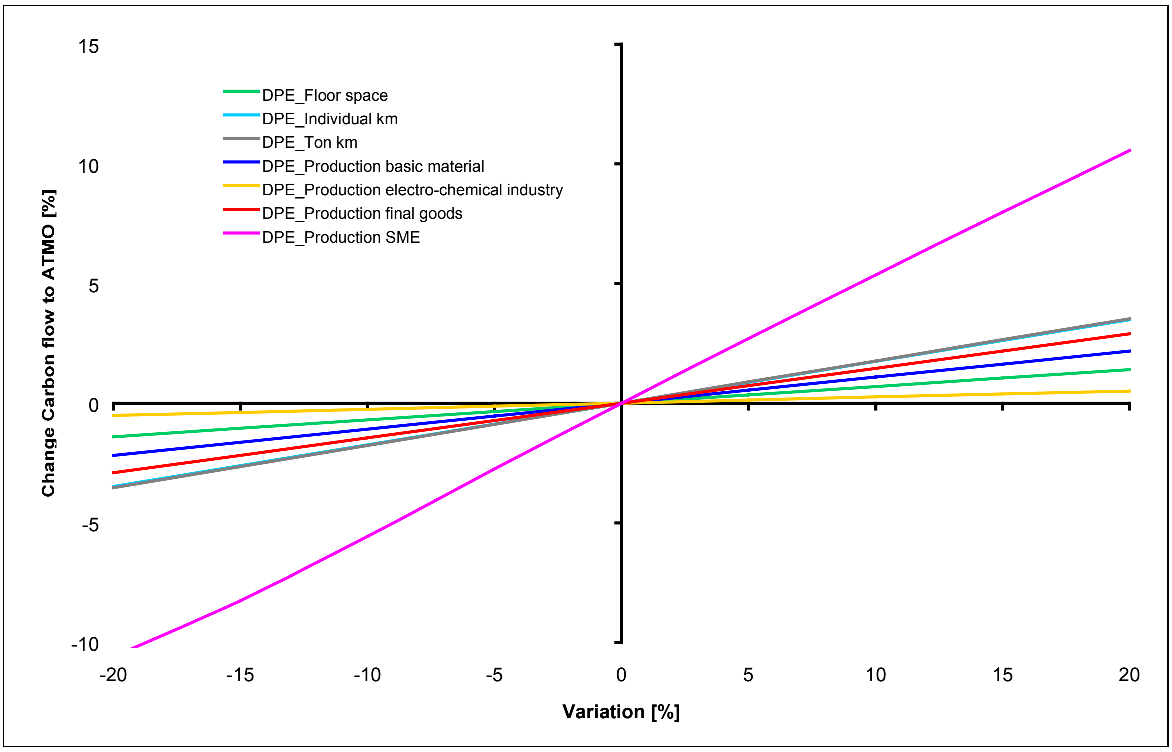


Figure A 3-36: Sensitivity analyses 1 + 2 - demand of useful energy – combination of productivity and energy services

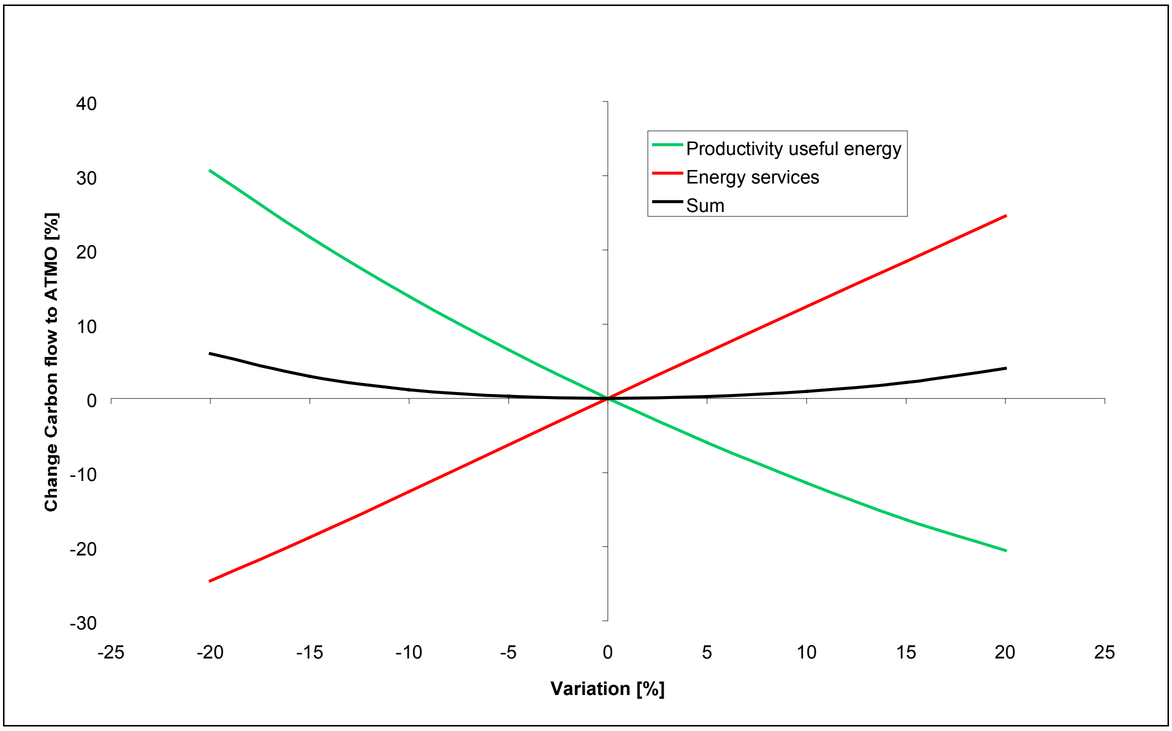


Figure A 3-37: Sensitivity analyses 3 - efficiency of energy transformation from final energy to useful energy (line of mechanical work and process heat lie almost in a pile, therefor the line of process heat is mainly to be seen)

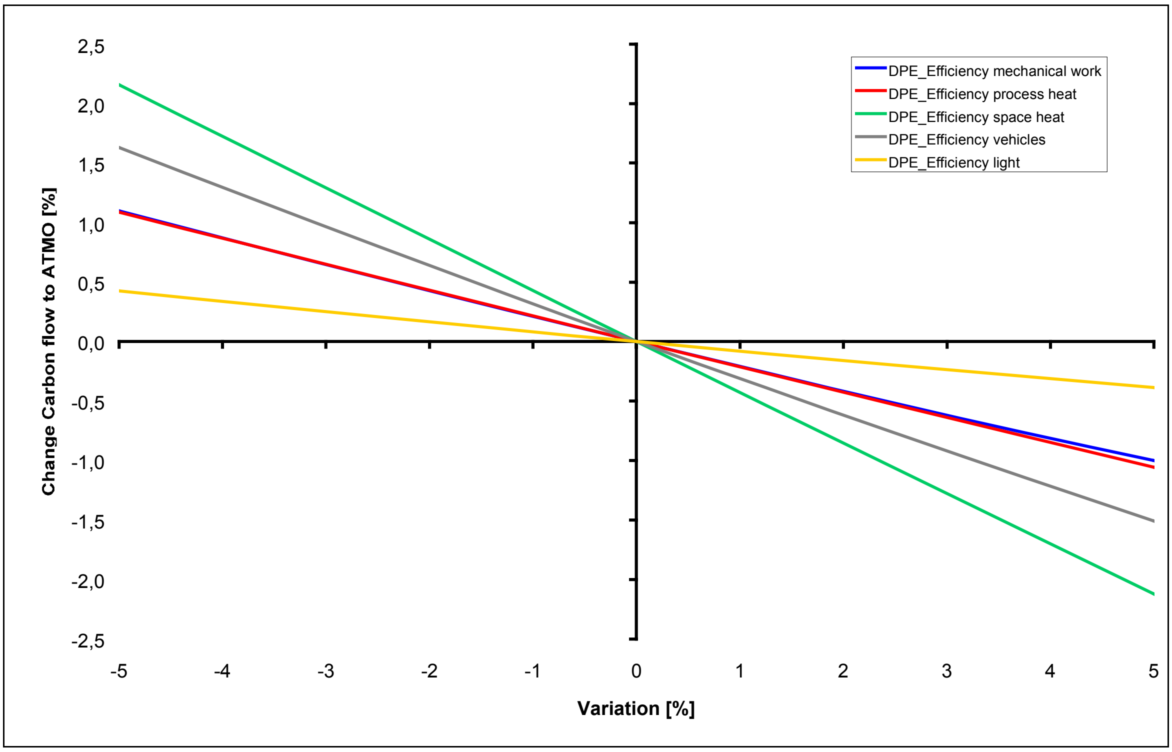
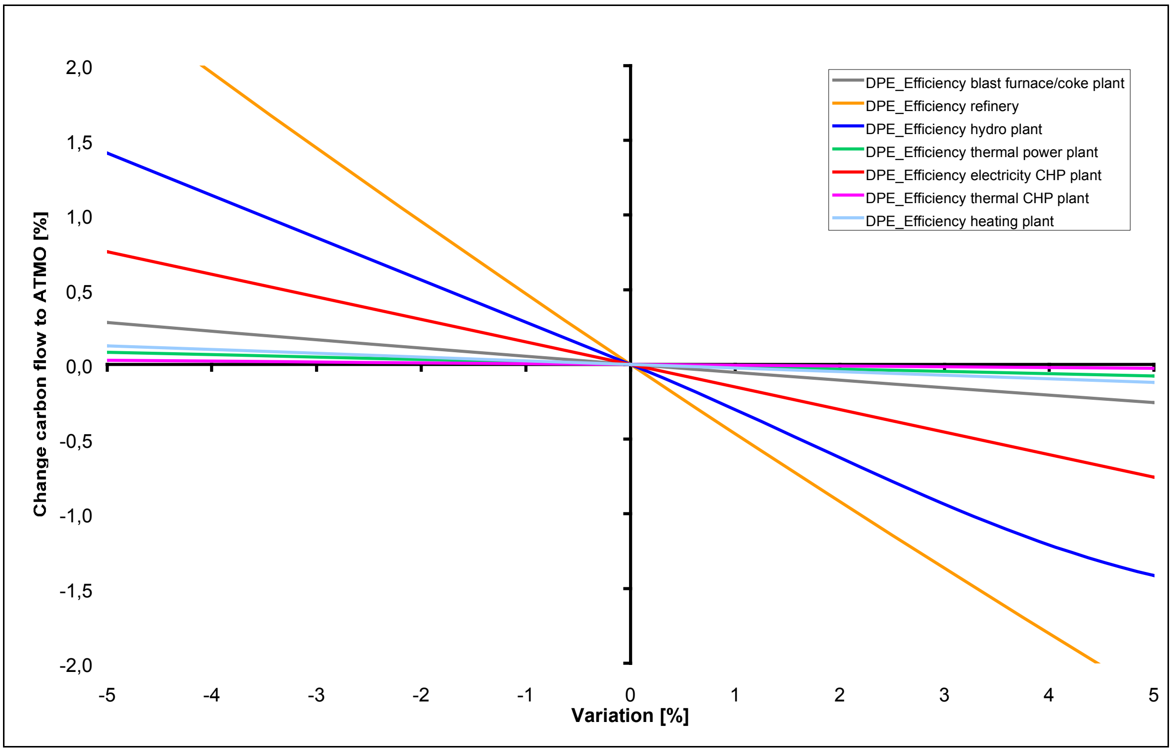


Figure A 3-38: Sensitivity analyses 4 - efficiency of energy transformation from primary energy to final energy



Uncertainty analyses

The database used for the modeling of the energy flows from the year 1990 to the year 1995 has an uncertainty of ± 2 PJ, which is mainly caused by rounding the data in the used energy flow in Austria (i.e. Energieverwertungsagentur 1993). This uncertainty in the energy flows is reflected in an uncertainty of the carbon flows between ± 0.03 – 0.056 MtC, depending on the affected energy carrier.

There is an inherent uncertainty in the amount of the biomass, mainly depending on the kind of biomass, the carbon content, the water content and the biomass used for heating in the residential sector. Uncertainties up to minus 20% are discussed (Bittermann 1999). These uncertainties mainly affect the biomass, that is used for space heat. In {ENERGY} this uncertainty is directly reflected in "EE_biomass space heat", in "ET_space heat" and in energy demand of "E_residential". But these uncertainties are about the same for the year 1990 to 1995 and also for the calculated years up to 2010. Therefore this inherent uncertainties do not effect the general trends and results from {ENERGY} and they are not treated in an uncertainty analyses.

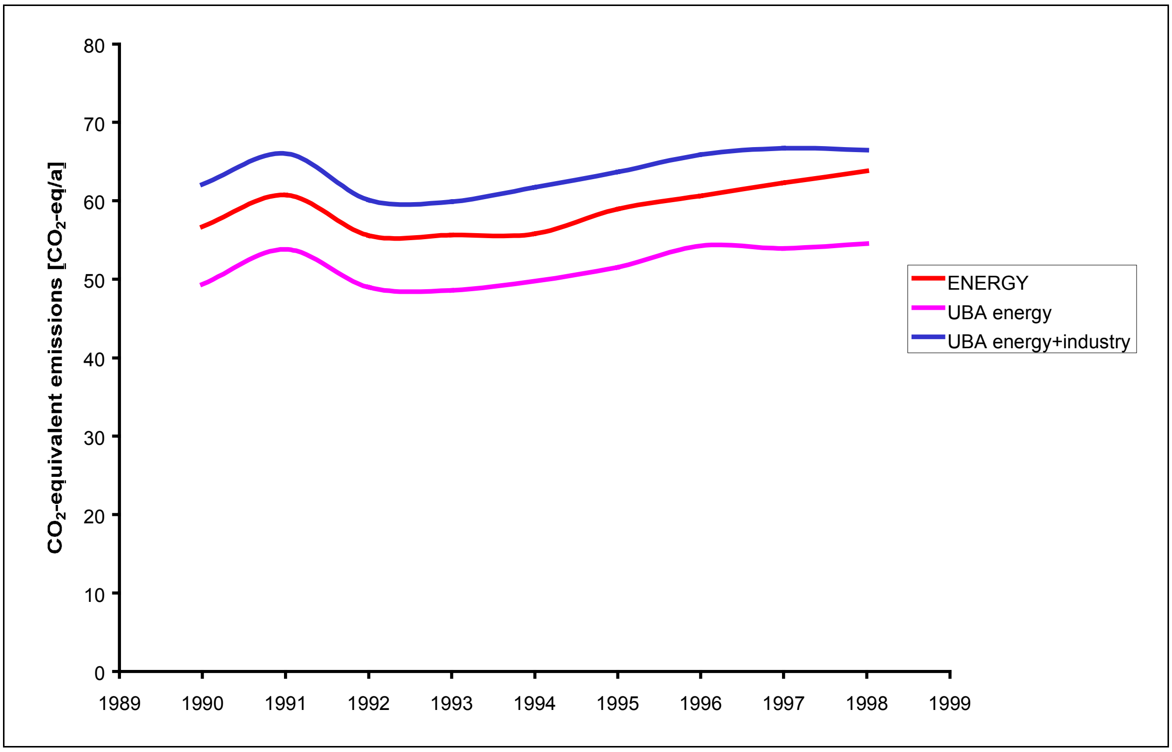
Further uncertainties are related to the inputs from other modules – FE_biomass, PE_biomass and WE_biomass. But these uncertainties are treated in the other modules. Because of the modeling strategy and concept of {ENERGY} – from energy services to primary energy – theses uncertainties may not be calculated automatically in {ENERGY}.

A 3-4 Discussion and Conclusions

A 3-4.1 Discussion

The model reflects the real development of the energy system between 1990 and 2000 quite well, which can be seen on the carbon emissions to the atmosphere (except from biomass combustion), that are comparable to the annual CO_2-equivalent emissions published by the Austrian Environmental Agency (UBA) (Figure A 3-39).The emissions of energy in Ritter et al. are lower, because some of the energy related emissions of industry are counted in industry, but in industry also process carbon emissions from steel and concrete industry are covered. That is why the results of {ENERGY} are just between these two lines. The future development until 2010 is strongly depending on the chosen assumptions for the need of energy services.

Figure A 3-39: Comparison of CO_2-equivalent emissions from Austrian Environmental Agency (UBA) and the results of {ENERGY}



A 3-4.2 Applicability of results

With the carbon modeling of the Austrian energy system the correlation of energy and carbon flows is demonstrated. All carbon flows in the energy system are calculated, and their future development is outlined. The main influences on the carbon flows in the energy system are described. The possibilities of the future development of the energy system and their related carbon flows are presented. The political options for reduction of greenhouse gases are reflected on the options to reduce the carbon flow from the energy system to the atmosphere.

The most promising option are the

- reduction of energy consumption with higher energy productivity and energy efficiency,
- use of renewable energy.

The increased use of biomass for energy leads to higher carbon emissions from the energy system, when gas or oil is replaced and leads to approximately the same emissions if coal is substituted. The advantage of carbon fixation of biomass is not reflected in the energy system, this effect is shown in the carbon uptake via photosynthesis in the agriculture and forestry sector.

The energy related carbon emissions to the atmosphere demonstrate in general, that very strong efforts in energy efficiency and in use of renewable energy must be implemented, because of the rapidly increasing demand of energy services. These strategies must already be strong to keep the carbon emissions constant by an increasing demand of energy services and must even be stronger to reduce the carbon emissions of energy use. The focus for future strategies must be mainly in transport sector with its rapidly growing number of vehicles and in residential sector with its huge demand for space heat and electricity. A successful implementation of energy and carbon measures in these fields will determine the overall success of a future sustainable development with lower carbon emissions from the Austrian energy system.

A 3-4.3 Priorities for future work

To get more desegregated results for certain fuels, sectors of economy and specific carbon reduction strategies, the model must be made more specific.

For the fuels the following specification might be added:

- different types of biomass, like wood chips, bark, biogas, rape methylester
- different types of coal like lignite, hard coal and coke,
- different types of oil, like heavy and light oil,

For the different sector of economy the details of the development of energy services and their energy demand might be modeled more specifically. This means, that not only the 3 main sectors – industry, residential and transportation – are modeled, but the 43 specific sectors of the economy (compare ÖSTAT 1992, ÖSTAT 1998, ÖSTAT 2000). This will have on one hand the advantage of a very detailed analyses and future outlook, but on the other hand the amount of data and assumptions will be enormous. This might only be successful if it is linked to economic energy modeling for these sectors.

For the development of more specific carbon reduction strategies, the driving parameter describing the productivity of useful energy, energy efficiency and increased use of renewable energy, must be more specified in detail. Then it might be possible to model detailed strategies of i.e. better thermal insulation of old and new buildings, increased installation of thermal solar systems for hot water etc.

A 3-5 References

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Annex 4

ACBM Modul FOREST

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A 4-1 Introduction

Of all terrestrial life zones forest ecosystems play the most important role in the global carbon cycle. As a consequence forest ecosystems as carbon sources or sinks are expected to influencing the national carbon exchange processes in a decisive matter. Between 60 and 80 % of the terrestrial carbon is sequestered by forest plants and soils *(Perruchoud et al., 1995).* Forest vegetation withdraws carbon dioxide from the atmosphere through the process of photosynthetic assimilation. Forest growth combined with the production of biomass accumulate carbon over a certain period of time, when carbon is stored in compartments of living vegetation, dead organic matter and the forest soil. In unmanaged forests, in the long run, the same amount of carbon dioxide is returned by the respiration of forest plants and the decay of organic matter in soil and litter compartments. Several forest carbon balance studies on global, continental and regional level are mentioned *(Kauppi (1992), Dewar and Cannel (1992), Burschel (1993), Nabuurs and Mohren (1993), Karjalainen et al.(1993), Dixon et al. (1994), Böswald (1996), Schöne et al. (1999).* In this study, the modeling of the Austrian forest ecosystems focuses on the description of the main processes that govern the role of vegetation, dead organic matter and soils in the forest as well as the utilization of biomass for energy use (link to the {ENERGY} module) and timber production (link to the {PROD} module) in the Austrian carbon cycle. Besides of other land utilization options especially the agricultural land use lies in a competition with forest areas. An exchange of areas represents the main connection to the {AGRO} module. To give an example of the importance of forest in the carbon cycle *Schwaiger et al. (1999)* found out that the forest management and ongoing timber and biomass utilization strategies offer opportunities to influence a national carbon balance. On the Basis of *Jonas (1997)* an improved dynamic modeling of the Austrian forest ecosystem is focused and described within this chapter for in the {FOREST} module.

By 1994, referring to the 1992/96 Austrian Forest Inventory - AFI *(Schieler et al., 1996,1997)* Austria is covered with forests by 47% of the national area, divided into exploitable and unexploitable forests. Within this study the module {FOREST} focuses only on the exploitable part of the forest, because it is assumed that unexploitable forests remain in an equilibrium referring to the carbon balance over time. The modeling in this module therefore covers around 85% of the Austrian forest area (3,924 Mio. ha), which is 3,352 Mio. ha. To avoid neglecting the harvests from non forest floor, the amount of fuelwood harvested there is added to the inventory increment data. It should be mentioned here that according to the forest act *(Bobek et al. (1998))* wind protection areas etc. are not forests and would be otherwise neglected of the entire carbon system. The Austrian forest is modeled as a “uniform high forest”, divided into coniferous and deciduous tree species in different age classes.

A 4-2 Methodology

A 4-2.1 Data availability

The main sources of available data for the {FOREST} module are the Austrian forest inventories, AFI *(Schieler et al., 1996,1997)* and data selected by *Körner et al. (1993).* Inventory data are predominantly used as input variables of forest areas, increment, initial growing stock, age class distribution and tree species. Forest utilization and harvesting data are taken from calculations of the ACDb project referring to *Jonas (2001).*

Data of the Austrian forest Inventory 1992/96 (see Table A 4-1) are taken for the calculation for several reasons: first it represents the most actual inventory, second the inventory period lies within the calculation time of the model and third *Jonas (2001)* showed that the inventories of both 86/90 and 92/96 are affected with high uncertainties. Therefore it has been decided to start with the inventory data of 92/96 to reach the most actual values of the Austrian forest.

Table A 4-1: Most important initial data for the {FOREST} module provided by the AFI 1992/96 *(Schieler et al., 1997)*

Tree species †)	Area [10^3ha]	Growing stock [10^3 m³ o.b.]	Gross annual increment [10^3 m³ o.b.]*)	Annual fellings‡) [10^3m³ o.b.]
Spruce	2039.6 ±*32*	606.347 ±*12.467*	17.304 ±*354*	12.125 ±*506*
Fir	85.2 ±*4*	45.601 ±*2.670*	1.071 ±*72*	979 ±*106*
Pine	244.8 ±*10*	89.076 ±*4.100*	1.941 ±*98*	2.000 ±*165*
Larch	160.6 ±*6*	67.322 ±*2.646*	1.592 ±*336*	1.027±*97*
Other C	4.5 ±*1*	519 ±*79*	19 ±*7*	1 -
Beech	337.8 ±*12*	90.766 ±*3.777*	2.223±*99*	1.377±*133*
Oak	73.0 ±*5*	23.258 ±*1.575*	598±*42*	449±*52*
B l r. [1]	250.2 ±*9*	39.611 ±*1.606*	1.403±*74*	761±*55*
B s r.[2]	156.3 ±*6*	25.410 ±*1.490*	1.187±*91*	842±*73*
Total	**3352.0 ±44**	**987.910 ±16.155**	**27.337±554**	**19.521±653**

†) Due to existing open woodland, scrub, shrub and brushland areas as well as predominant growth, number are corrected following the method of Jonas et al. (1997).

**) the increment refers to the forest area for each tree species provided by the Austrian Forest Inventory.*

‡)The term "Annual fellings" in this table represents the decrease of growing stock (natural losses, calamities, thinning and final felling). It is mentioned that for the modeling data forest fellings are reported by the {PROD} and {ENERGY} module, following the calculations of Jonas M. (2001).

The inventory provides data of growing stock per tree species, area and age class, but it does not contain values of increment and fellings per tree species and age class essential for the modeling. This knowledge gap was closed by using available yield tables of *Marschall (1992)* as described in chapter A 4-2.2.

Within the {FOREST} module different types of data can be distinguished:

- Model variables
- Driving parameters

---

[1] Blr: this group of tree species is represented by non coniferous (broadleaf) species with an assumed long rotation lengths (l.r.), similar to the Berman "Hartlaub" (maple, elm, ash etc.) provided by the AFI (*Schieler et al. 1996, 1997*)

[2] Bsr: this group of tree species is represented by non coniferous (broadleaf) species with an assumed short rotation lengths (s.r.) and similar to the German "Weichlaub" (alder, poplar, birch etc..) provided by the AFI (*Schieler et al. 1996, 1997*)

- Internal parameters

Model variables, like pools, fluxes or areas, contain the output of the model and are initialized at the beginning of the simulation with values taken from of the forest inventory as indicated above. Driving parameters are defined according to the "Driving Force" scenarios and described in further detail under the scenario section.

Table A 4-2: Overview of the used internal model parameters (see also specific part in chapter A-4.6)

Name	Symbol	Description	Dimension/ Unit	Range*	Literature Source
Rotation time	τ	Inflection point of harvest function	[yr]	Species	Assumption
Sigma	σ	Curvature of harvest function	[-]	Species	Assumption
Slash Use	χ	Used fraction of total slash production	[%]	species	Set to reach *Bittermann et al. (1995)*
Harvest losses	β	Fraction of stem wood lost during harvest	[%]	species	*AFF (2000)*
Root fraction	ε^r	Dentromass fraction of root biomass	[%]	Species, age class	*Körner et al. (1993)*
Small branch fraction	ε^b	Dentromass fraction of small branches	[%]	Species, age class	*Körner et al. (1993)*
Foliage fraction	ε^f	Dentromass fraction of foliage	[%]	Species, age class	*Körner et al. (1993)*
Density	f^d	Density of absolute dry wood	[kg/m^3]	species	*Lohmann et al. (1986)*
Carbon content	f^c	Carbon contend of absolute dry wood	[%]	species	*Gottlieb (1883)*
Heating value	LHV	Heating value of absolute dry wood	[MJ/kg]		*Jonas et al. (1994)*
Foliage turn over rate	ρ^f	Reciprocal life time of foliage	[1/yr]	species	*Schmidt-Vogt (1986)* Assumptions
Branch turn over rate	ρ^b	Reciprocal life time of small branches	[1/yr]	species	Assumptions
Non woody litter decomposition rate	δ^{nwl}	Decomposition rate of carbon in non woody litter pool	[1/yr]	-	Assumptions
Woody litter decomposition rate	δ^{wl}	Decomposition rate of carbon in the woody litter pool	[1/yr]	-	Assumptions
Active mineral soil respiration rate	δ^{asr}	Decomposition rate of carbon in active mineral soil pool	[1/yr]	-	Assumptions
Stabilized mineral soil respiration rate	δ^{ssr}	Decomposition rate of carbon in the stabilized mineral soil pool	[1/yr]	-	Assumptions
Mineralization fraction of woody litter	b^{branch}	Percentage of woody litter decay flowing into the stabilized mineral soil pool	[%]	-	*Schlamadinger (1996)*
Mineralization fraction of non woody litter	b^{foil}	Percentage of non woody litter decay flowing into the active mineral soil pool	[%]	-	*Schlamadinger (1996)*

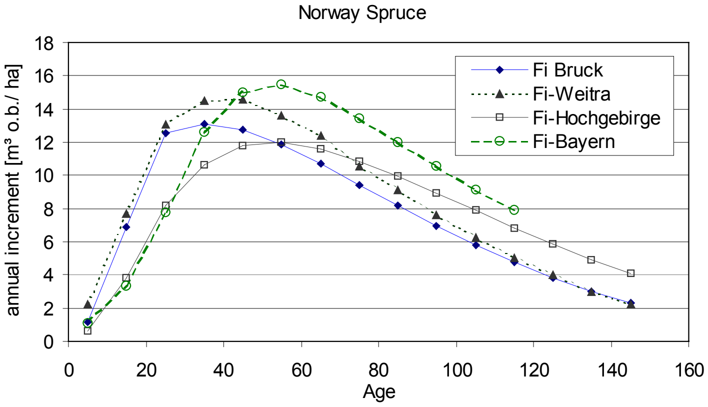
In contrast to model variables and driving parameters, internal parameters are used in the model equations and do not vary over time. Table A 4-2 gives an overview of the internal model parameters of the {FOREST} module, their use in the equations is described under the section model design and the values are presented and the end of this appendix. The scope of internal parameters differs, while some are scalars others are species specific or species and age class specific. This is expressed under the column denoted “Scope”.

A 4-2.2 Data and knowledge gaps

Forest growth

The principal data basis of the {FOREST} module, the Austrian forest inventory, provides increment and thinning data only per species area, but not per age class and species. But since the latter is essentially required by the model concept, this data gap had to be closed with the aid of yield tables, which provide an information about the partition of total wood production (GWL) among the age classes shown in Figure A 4-1 *(Marschall, 1992)*.

Figure A 4-1: Example for annual increments between the age of 10-150 years for Norway spruce and for different growing districts in Austria provided by the yield tables of *Marschall (1992).*



Some may argue that yield tables are old and thinning regimes have changed. If yield tables are old, it is likely that the growth has changed, also same management may not be applied as in the past. It should be pointed out here that yield tables are only used to distribute thinning and increment data per tree species on the choosen age classes. The absolute amounts of tree species increments and thinning are provided by the AFI.

For example the growth of Norway spruce, the most important tree species in Austria, is represented by four different yield tables, applicable to different growth regions. Therefore a selection and weighting of yield tables depending on the distribution of spruce covered forest areas has been done. Forests in Austria can be subdivided into nine different growing districts, depending on climate, soil conditions, geology etc. For each growing district and subdistrict yield tables can be classified. Data of the Austrian Forest Inventory can be classified for all political districts. In a first step those political districts are distributed to the Austrian growth districts to specify the appropriate yield tables. Second, depending on the forest areas the choosen yield tables were weighted. This resulted in a derivation of the variable $z_{s,k}$ (for increment) and $t_{s,k}$ (for thinning), which prescribe the GWL_s and the USE_s (= the sum of intermediate felling), which are normalized to:

$$\sum_k z_{s,k} = 1 \quad \text{and} \quad \sum_k t_{s,k} = 1$$

$z_{s,k}$ and $t_{s,k}$ just contain the information about shape of the increment (thinning) distribution over age of the species s, as derived from the yield tables which are supposed to represent the growth behavior.

The following equations and steps are used to receive actual increment and thinning data per tree species and age class (the equation refer to the calculation of increment, calculations of thinning data are carried out in the same way).

The overall Increment I, of the production forest is the sum of the increments I_s of all species as reported by the AFI:

(1)
$$I = \sum_{s=1}^{M} I_s$$

Given variables from the weighted yield tables:

- GWL_s [m³/ha] Sum of increments over all classes in the yield table
- $z_{s,k}$ [-] Portion of increment of species s and age class k on total GWL_s as derived from yield tables

Given variables provided by the Austrian yield tables and the AFI:

- I_s [m³] Increment of species s, as reported from the inventory
- $a_{s,k}$[ha] Area of species s in age class k

Missing variable needed for the modeling:

- $i_{s,k}$ [m³/ha] Increment of species s per age class k

The basic relation between I_s and $i_{s,k}$ is given in equation 2:

(2)
$$I_s = \sum_{k=1}^{N} (i_{s,k} \cdot a_{s,k})$$

When in yield tables GWL_s is the sum of all wood produced during one rotation period passing over all age classes with $z_{s,k} > 0$, the following equation can be established:

(3)
$$i_{s,k} = \frac{1}{20} \cdot GWL_s \cdot z_{s,k}$$

Inserting equation (3) into the basic equation (2) leads to equation (4):

(4)
$$I_s = \frac{1}{20} \sum_{k=1}^{N} (GWL_s \cdot z_{s,k} \cdot a_{s,k})$$

which might be easily transformed into equation (5):

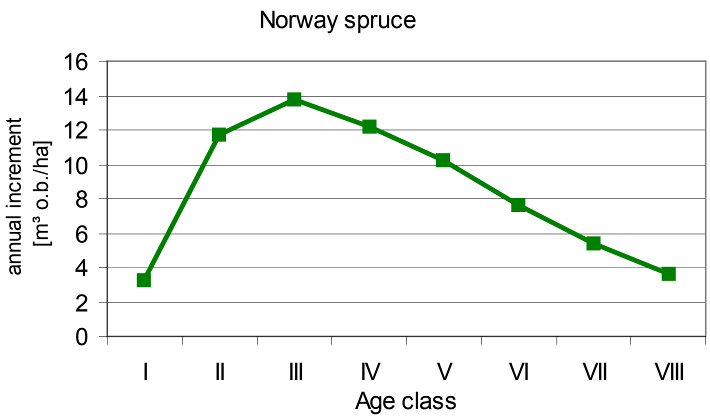
(5)
$$GWL_s = 20 \cdot \frac{I_s}{\sum_k (z_{s,k} \cdot a_{s,k})}$$

then substituting GWL_s in equation (3) results in the final equation (7):

(7)
$$i_{s,k} = \frac{z_{s,k} \cdot I_s}{\sum_{k=1}^{N} (z_{s,k} . a_{s,k})}$$

The $i_{s,k}$ are then taken for the calculation of the age class dependent increment in the model (see Figure A 4-2), where they - together with the 1990 age class distribution - reproduce the I_s values found in the inventory.

Figure A 4-2: Resulting growth curve of the calculation described above, here for the example of Norway spruce



Net primary productivity (NPP)

Forest inventories rather report values of increment than of net primary production (NPP). Beside the fact that increment data are given in cubic meters over bark [m³ o.b.], whereas NPP is expressed in kg carbon [kg C], the most important difference is that increments only cover the exploitable wood (over a diameter of 5 cm of the Austrian Inventory), whereas NPP includes all parts of forest tree biomass (dentromass). As a flux value, NPP further includes the production of assimilation organs (leaves/needles), which makes quite a huge fraction of NPP and other material that is lost each year. Since the ACBM is a carbon flux model it unavoidable requires the use of NPP, which therefore had to be calculated from increment data. First increment data given in cubic meters can easily be converted into kg of C using conversion factors (f_c), density (f_d) and expansion factors accounting for small branches,ε^b, foliage, ε^f, and for roots ε^r. Due to the age dependency of expansion factors, ε^b and ε^f also permit the calculation of the foliage and the small branch fraction of a stand at a certain age. These fractions are the reservoirs for the annual litter production to be added to the increment. The only information left was the life time (or the turn over rate, respectively) of these reservoirs. It was assumed, that if a spruces needle remains 10 years on the tree every year, 1/10 is shed in form of non woody litter production. In the case of deciduous tree species (and for larch) the turn over rates of foliage is evident. But for needle leafed species the literature only provides data for spruce (*Schmidt-Vogt,1986)*. Values referring to fir, Other C and pine had to be assumed intelligently. In this way the turn over rate of pine is set to be 5 years, for other coniferous tree species this value is assumed to be equal to Norway spruce.

Forest soil system

The soil carbon system of forest is one of the most uncertain parts of the model. Whereas the absolute amount of carbon content per area is relatively well known *(Englisch (1992); Weiss (2000); Jonas (1997), Körner et al. (1993); Blum et al. (1997),* little is known about the dynamic of forest soils in middle Europe. Sometimes it is assumed that forest soil carbon content still recovers from ancient suffering due to anthropogenic removing of dead organic matter. *Burschel (1993)* reports influences on forest carbon stock due to forest pasturing. Therefore it is not sure, weather the current forest carbon stock has reached an equilibrium, even these extra land use activities in forests have been decreasing in this century. On the other hand, the response of soil carbon to the dynamics of vegetation is not clear. Some may argue that due to an increase of soil respiration after clear cutting the C-content of this areas decreases significantly *(Freibauer, 2000)*. However, *Bauer (1989)* found out that soil carbon contents of managed spruce stands of different age classes do not differ significantly in their soil carbon content.

This is therefore all subjected to modeling, based on the assumptions that litter production and harvesting represents an input in the dead organic matter pool due to the slash left on forest ground and that for example a younger stand has less litter production than older ones. Non coniferous stands have other dynamics of non woody litter productions than coniferous etc. .

The modeling of the soil carbon dynamics of Austrian forests is guided by the assumption that in the initial year (1990) fluxes into the soil system (litter and harvest residues) balance the respiration and leaching fluxes leaving the system. Furthermore, an equilibrium is assumed for all four soil pools calculated within the {FOREST} module. In fact, the equilibrium needs not to be attributed to every age class area, but it is assumed, that overall forest soil carbon is in a dynamic equilibrium, considering that there might be areas with increasing soil carbon stock and others with a decreasing dynamic, finally balancing each other to the assumed equilibrium. This idea might be justified by the fact that Austrian forests age class distribution does not widely deviate far from a normal forest situation and that the soil carbon system reacts slowly on changes in age class distributions.

Since initial data of average soil carbon pools sizes are provided by *Körner et al. (1993)*, the assumption of an equilibrium of soil carbon corresponding to the initial age class distribution allows for a calculation of soil respiration rates. The thus defined equilibrium belongs to the age class distribution and the utilization of the initial year and would endure if there would not be changes in forest structure and management strategy.

It is supposed, that soil carbon system reacts slowly and that no major changes in utilization leading to extremely different input fluxes, so that only disturbances of the soil carbon system are to be considered, which evolve from moderate changes in forest utilization and management practices.

On the basis of the available mean values for the tree species of spruce, beech, pine and oak the total carbon values shown in Table A 4-3 are used as initial soil carbon contents for the defined carbon pools of the forest soil system (see chapter A 4-2.3). Note that for other tree species average values are assumed.

Table A 4-3: Initial soil and dead organic matter pools in Austria for different tree species in the year 1990 based on area data of Table A 4-1

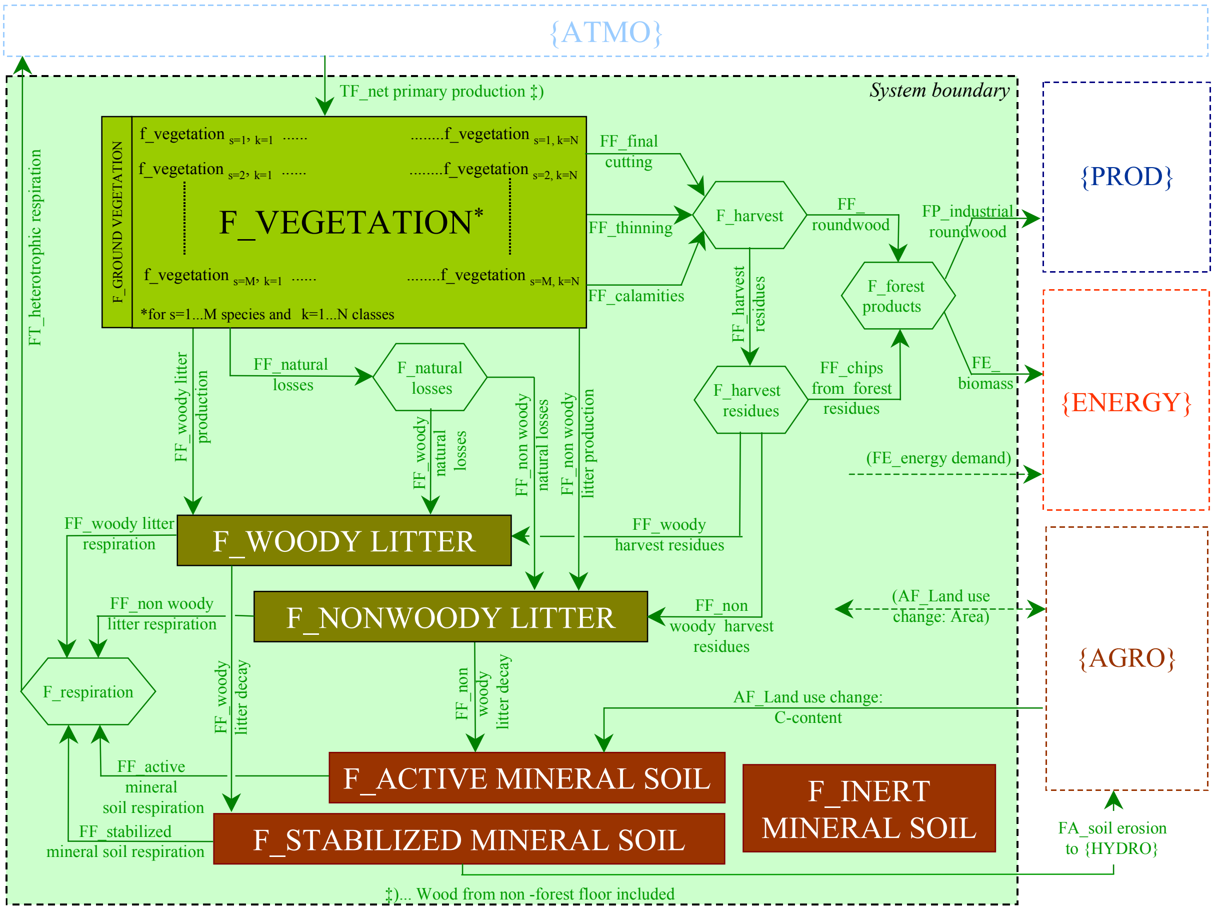
Depth: 50 cm	Area (%)	Carbon of mineral soil [tC/ha]	Dead organic matter (litter) [tC/ha]	Total [tC/ha]
Spruce	60.8%	113 ±5,7	23.4 ±3.9	135 ±7.1
Fir	2.5%	113 ±5,7	23.4 ±3.9	135 ±7.1
Pine	7.3%	47 ±6.3	25.0 ±5.8	72 ±6.9
Larch	4.8%	113 ±5,7	23.4 ±3.9	135 ±7.1
Other C	0.1%	113 ±5,7	25.0 ±5.8	135 ±7.1
Beech	10.1%	97 ±6.0	11.9 ±1.6	106 ±6.9
Oak	2.2%	95 ±6.0	15.6 ±6.0	102 ±15.9
B l r.	7.5%	96 ±6.0	13.8 ±6.2	104 ±17.3
B s.r.	4.7%	147 ±15.6	3.1 ±0.5	151 ±21.0
Area weighted mean value	**100%**	**106.5 ±17.0**	**20.5±13.9**	**127.0±35.9**

Jonas (1997) reported an average area weighted mineral soil carbon content of 131t/ha for coniferous and 106 tC/ha for deciduous forests for the period 1986/90. Dead organic matter pools are given as one mean value with 12 tC/ha. For comparison *Glatzel and Chen (1998)* respectively *Fizek (1990) report* 24.4 tC/ha and 4.8 – 23.9 tC /ha for different spruce stands in Austria. *Jonas (2001)* indicated an age class weighted average soil carbon content of the Austrian yield forest with 406 (±3.8%) Mio tC witch corresponds to 122 tC/ha. For comparison, *Weiss (2000)* reported an average amount of 121 tC/ha for afforestation, deforestation and reforestation area (up to 50 cm depth) with 106 tC/ha for the mineral soil and 15 tC/ha for the dead organic matter fraction. At the moment the Austrian soil inventory (ASI) *(Englisch, 1992)* only provides concentrations of carbon stocks in forest soils. Therefore these data have to be converted by using conversion factors (densities etc.) for different soil types. *Weiss (2000)* underlines that due to an estimation (no measurement has taken place) of the conversion parameters lead to highly uncertain data of soil carbon contents. The mean carbon content of Austrian forests used and calculated for the {FOREST} module are therefore in the same range.

A 4-2.3 Model design

The behavior of the {FOREST} module, defined as the total ecosystem of the exploitable Austrian forest, is directly driven by parameters defined according to the driving force scenarios (No major changes, Towards sustainability) which aim to describe future trends in forest management.

Figure A 4-3: Concept of the {FOREST} module– carbon flows and pools considered within the Forest sector



Furthermore, as part of the ACBM structure, the {FOREST} module is indirectly influenced by the driving parameters defined within all other ACBM modules. The linkages are the demand of domestic roundwood production from the {PROD} module and the fuel wood consumption calculated by the {ENERGY} module. Form the {FOREST} model point of view, “FP_industrial roundwood”, “FE_biomass” and “AF_land use change” are additional driving variables which govern the output of {FOREST} module directly. Within the system boundaries of the {FOREST} module 6 carbon pools are defined, five soil carbon pools containing dead organic matter and one vegetation pool. The vegetation pool is divided into the main part F_VEGETATION, representing the growing stock of the Austrian exploitable forest (tree biomass) and F_GROUND VEGETATION, covering the annual or perennial species growing on forest floor. Representing the forest soil two different dead organic matter pools (F_WOOD LITTER and F_NON WOODY LITTER) and three different mineral soil organic matter pools – F_ACTIVE MINERAL SOIL, F_STABALIZED MINERAL SOIL, and F_INERT MINERAL SOIL are defined. The latter is imported from the {AGRO} module and not modeled within the {FOREST} module.

Figure A 4-3 shows the structure of the {FOREST} module in further details, boxes represent the included pools, whereas arrows symbolize fluxes connecting pools and/or dispatcher. A dispatcher splits or collects a number of different fluxes. Pools are calculated by adding incoming fluxes and subtracting carbon fluxes leaving. Boxes with dotted lines represent other modules or the atmosphere {ATMO}. The modules {PROD} and {ENERGY} are only acceptors of carbon fluxes from {FOREST}, but {ATMO} and {AGRO} receive carbon as well as they are sources of carbon for the module {FOREST}.

All fluxes and pools are internally calculated in units of kg carbon (kg C), input values of forest data usually given in m³ of wood over bark are therefore first transformed by using expansion factors, densities and carbon content parameters for each species. This “transfer” is described in section A 4.2.1 “Data availability”. While soil pools are relatively simple and unstructured, the F_VEGETATION box (Figure A 4-3) shows that an age class structure is laying behind the overall pool for different tree species, modeled by increment and harvesting functions over time. Below, further details of the carbon pools within the {FOREST} module system boundaries are described:

Carbon pools in detail

F_VEGETATION

The calculation of all fluxes associated with F_VEGETATION is connected to the underlying age class structure. According to the yield table oriented approach, the calculation of “TF_net primary production”, “FF_calamities”, “FF_thinning” and “FF_natural losses” is based upon age class parameterized values of:

$NPP_{s,k}$ [kgC/ha]	Net primary production per hectar of species *s* in age class *k*
$Thin_{s,k}$ [kgC/ha]	Thinning applied to one hectar of species *s* in age class *k*
$Cala_{s,k}$ [kgC/ha]	Calamity losses per hectar of species *s* in age class *k*
$NatL_{s,k}$ [kgC/ha]	Natural losses per hectar of species *s* in age class *k*

The following equations (8-11) depict the calculation of the fluxes which only dependent on age class distribution of area, denoted as $a_{s,k}$ [ha]:

$$TF\_net\ primary\ production = \sum_{s=1}^{M}\sum_{k=1}^{N}(a_{s,k} \cdot NPP_{s,k}) \tag{8}$$

$$FF\_thinning = \sum_{s=1}^{M}\sum_{k=1}^{N}(a_{s,k} \cdot Thin_{s,k}) \tag{9}$$

$$FF\_calamities = \sum_{s=1}^{M}\sum_{k=1}^{N}(a_{s,k} \cdot Cala_{s,k}) \tag{10}$$

$$FF\_natural\ \ losses = \sum_{s=1}^{M}\sum_{k=1}^{N}(a_{s,k} \cdot NatL_{s,k}) \tag{11}$$

In contrast to equations 8 to 11, the fluxes “FF_final cutting”, “FF_woody litter production” and “FF_non woody litter production” do not only depend on age class distribution and are related to the values of $f\_vegetation_{s,k}$, which is the biomass density of species s in age class k in [kg C/ha]. This value is time dependent as stands grow and experience an increment as well as losses like thinning, calamities natural losses and so on. Equation (12a) presents the development of biomass density $f\_vegetation_{s,k,t}$ as a function of previous biomass density (defined as the growing stock per area) on stand k-1 at time t-1, which was managed with an increment $NPP_{s,k}$, thinning intensity $Thin_{s,k}$ and so on:

(12a)

$$\begin{aligned} f\_vegetation_{s,k,t} = {} & f\_vegetation_{s,k-1,t-1} \\ & + a_{s,k-1,t-1} \cdot (NPP_{s,k-1} - Thin_{s,k-1} - Cala_{s,k-1} - NatL_{s,k-1}) \qquad for \quad k = 2 \ldots N \\ & - f\_vegetation_{s,k-1,t-1} \cdot (\rho^f_{s,k-1} \cdot \varepsilon^f_{s,k-1} + \rho^b_{s,k-1} \cdot \varepsilon^b_{s,k-1}) \end{aligned}$$

The afforested or reforested stands with k=1 start with:

(12b) $$f\_vegetation_{s,k=1,t} = 0$$

In equation (12a) ε^b and ε^f symbolize the (small) branch fraction and the foliage fraction of entire dendromass. Thus *$f\_vegetation_{s,k}$* x ε^b gives the biomass (in kg C) of the small branches and *$f\_vegetation_{s,k}$* x ε^f the foliage biomass. Multiplication with the mean turn over rate of foliage ρ^f or small branches, ρ^b, leads to the annual litter production fluxes “FF_woody litter production” and “FF_non woods litter production”.

(13) $$FF\_non\ woody\ litter\ production = \sum_{s=1}^{M} \sum_{k=1}^{N} \rho^f_k \cdot \varepsilon^f_k \cdot f\_vegetation_{s,k}$$

(14) $$FF\_woody\ litter\ production = \sum_{s=1}^{M} \sum_{k=1}^{N} \rho^b_k \cdot \varepsilon^b_k \cdot f\_vegetation_{s,k}$$

As all fluxes to and from the F_VEGETATION pool are defined, the balance of the pool is calculated by using the biomass density *$f\_vegetation_{s,k}$*. With proceeding time, an excess of increment (NPP) over losses will lead to an increase of biomass density (or as multiplied by the area a_{sk} to an accumulation in standing stock). Calculation of the F_VEGETATION pool results from summarizing all products (*$a_{s,k}$* x *$f\_vegetation_{s,k}$*) including *s* = 1 ... M species and *k* = 1 ... N age classes, as depicted in equation (15):

(15) $$F\_VEGETATION = \sum_{s=1}^{M} \sum_{k=1}^{N} a_{s,k} \cdot f\_vegetation_{s,k}$$

Carbon stock change in F_VEGETATION, which occurs due to an increase of biomass density (on the terms in *$f\_vegetation_{s,k}$* per ha) leaves the system, if an area is submitted to clear cut felling. Calculation of “FF_final harvest” is therefore described below under the section “Age class propagation”.

Age class propagation

All fluxes entering or leaving the F_VEGETATION pool depend on the distribution of areas among age classes. Since age classes are internally interpolated to the width of 1 year, they match the models time step and age class progression is easy calculated using a matrix formalism *(Kohlmaier et al., 1995).*

Starting with the initial distribution given by the inventory, age classes of the following year can be calculated when knowing the annual mortalities (m_k) of all age classes as shown below:

(16)

$$\begin{pmatrix} f_s \cdot a_1 \\ a_2 \\ . \\ . \\ . \\ a_N \end{pmatrix}_{s,t=n+1} = \begin{pmatrix} m_1 & m_2 & . & m_i & . & 1 \\ 1-m_1 & 0 & . & 0 & . & 0 \\ 0 & 1-m_2 & . & . & . & 0 \\ . & 0 & . & 0 & . & . \\ . & . & . & 1-m_i & . & . \\ 0 & 0 & . & 0 & . & 0 \end{pmatrix}_{s,t=n} \cdot \begin{pmatrix} a_1 \\ a_2 \\ . \\ . \\ . \\ a_N \end{pmatrix}_{s,t=n} \qquad for\ s = 1 \ldots M$$

The matrix on the right hand side of equation (16) is a so called Leslie Matrix *(Leslie,1945)*, which contains as coefficients the possibility m_k of transition from age class a_k into the a_{k+1}. Note that in contrast to the usual formulation the first component of vector a_{t+1} is multiplied by a factor f_s indicating either reforestation or afforestation share of species s. If $f_s = 1$ the species s would keep it's initial area.

Mortalities: The discrete values of the mortality coefficients m_k within the Leslie Matrix can be calculated using different "harvest functions" of the type $m_k = fkt(k)$. It turns out, that for the ACBM {FOREST} module purpose a tangens hyperbolicus function leads to the best results, especially when "FF_final harvest" is an external demand (see below). equation (17) denotes sigmoid the used harvest function:

$$m_{s,k} = A_s \cdot 1 - \frac{tanh(\sigma_s \cdot (\tau_s - k))}{2} \tag{17}$$

Where A_s is the so called amplitude factor which determines the transition coefficient $m_{s,k=\infty}$, The curvature is given by σ_s and τ_s is inflection point identified with the rotation period of the species s. The parameters curvature (σ_s) and rotation length τ_s depend only on species type and are kept constant throughout the whole simulation.

Calculation of FF_final harvest

The amplitude factor A_s is used to calculate the area which has to be clear cut in order to serve the wood demand of "FE_biomass" and "FP_roundwood". The model first determines the fraction of F_VEGETATION that has to be harvested taking into account thinning, accidental use, wood from non forest floors and all harvesting losses. Then the area that has to be clear cut is calculated by adapting the parameter A_s in equation (18) for every species and in every simulated year. An increase of A_s rises the area which is finally harvested. Therefore the flux "FF_final harvest" is evaluated by:

$$FF\_final\ harvest = \sum_{s=1}^{M} \sum_{k=1}^{N} m_{s,k} \cdot a_{s,k} \cdot f\_vegetation_{s,k} \tag{18}$$

Now that all fluxes directly linked to the F_VEGETATION pool are present, the equations for the time dependence of $f\_vegetation_{s,k}$ can be described: The $f\_vegetation_{s,k}$ pools follow the area vector subjected to the matrix formalism (see equation (16)), where the biomass is passed from one age class to the next as time proceeds from year to year. The new $f\_vegetation_{s,k}$ is then calculated from the pool k -1 of the last year by adding and subtracting the fluxes of the proceeding year.

Every reforested area starts with no initial biomass content, the accumulation is just the NPP of the first age class minus losses due to thinning, calamities and natural losses throughout the first year. Note that the balance of NPP and wood use is responsible for an increase or decrease of stand biomass density over time. For example, a thinning rate below it's yield table level will result in a accumulation of stand biomass density.

Other carbon pools

The forest floor continuously receives dead organic matter from the tree in form of foliage, branches, stems, woody and non woody below ground biomass (roots), which consequently decompose in processes of soil formation. The following defined carbon pools assimilate these fluxes of growing stock releasing shares of dead organic matter ("litter") decay to both atmosphere and soil organic matter pools.

F_WOODY LITTER

The F_WOODY LITTER pool, representing the woody parts of dead organic matter pool is filled by carbon from the leaf/needle fraction of the living biomass entering the pool as the flux "FF_woody litter production" (equation (19)). Additional sources are woody parts of the natural losses (including roots) defined as "FF_woody natural losses" and not removed woody parts of harvest residues remaining on ground as "FF_woody harvest residues".

The material is decomposed under production of CO_2 ("FF_woody litter respiration") and another flux, defined as "FF_woody litter decay", heading into the F_STABILIZED MINERAL SOIL pool.

(19)
$$\begin{aligned} F\_WOODY\ LITTER_t = F\_WOODY\ LITTER_{t-1} & \\ + FF\_woody\_litter\_production & \\ + FF\_woody\_natural\_losses & \\ + FF\_woody\_harvest\_residues & \\ - FF\_woody\_litter\_decay & \\ - FF\_woody\_litter\_respiration & \end{aligned}$$

The flux "FF_woody litter production" is defined above. Calculation of "FF_woody natural losses" and "FF_woody harvest residues" is described below under the section dispatchers – "F_natural losses" and "F_harvest residues". Respiration and decay of the pool follow a donor controlled approach:

(20)
$$FF\_woody\_litter\_decay = b^{branch} \cdot \delta^{wl} \cdot F\_WOODY\_LITTER$$

(21)
$$FF\_woody\_litter\_respiration = \left(l - b^{branch}\right) \cdot \delta^{wl} \cdot F\_WOODY\_LITTER$$

In these equations β_s denotes the plant type specific harvest processing losses. This harvest losses only apply to the net harvest, which is the stem wood fraction ($1-\varepsilon^r - \varepsilon^f - \varepsilon^w$) of the dentromass. Usually β_s values range between 0.75 and 0.85.

The δ^{wl} is the overall decay rate of the F_WOODY_LITTER pool, it is given in [1/yr]. The b^{branch} factor splits the entire decay flux into two fluxes: "FF_woody litter decay" and "FF_woody litter respiration" (equations (20, 21). The latter heading towards the atmosphere and the first going to the F_STABILIZED MINERAL SOIL pool.

F_ NON WOODY LITTER

Has the same structure as it's woody counterpart, only dealing with carbon of the non woody material. The difference lies in the decomposition rate of stored carbon, which is – due to easier decay of the material – higher then for the "F_woody litter". The decomposed woody litter that is not respired as "FF_non woody respiration" (entering the "F_respiration" dispatcher) flows into the F_ACTIVE MINERAL SOIL pool.

The structure of the balance is very much the same as for the F_WOODY LITTER POOL (equation (22)):

$$
\begin{aligned}
F\_NON\_WOODY\ LITTER_t = {} & F\_NON\_WOODY\ LITTER_{t-1} \\
& + FF\_non\_woody\_litter\_production \\
& + FF\_non\_woody\_natural\_losses \\
& + FF\_non\_woody\_harvest\_residues \\
& - FF\_non\_woody\_litter\_decay \\
& - FF\_non\_woody\_litter\_respiration
\end{aligned}
\tag{22}
$$

The calculation of the fluxes "FF_non woody litter production", "FF_non woody natural losses" and "FF_non woody harvest residues" is described under the section dispatchers – "F_natural losses" and "F_harvest residues", see below. Respiration and decay of the pool follow a donor controlled approach:

$$FF\_non\_woody\_litter\_decay = b^{foliage} \cdot \delta^{nwl} \cdot F\_WOODY\_LITTER \tag{23}$$

$$FF\_non\_woody\_litter\_respiration = \left(1 - b^{foliage}\right) \cdot \delta^{nwl} \cdot F\_WOODY\_LITTER \tag{24}$$

The structure of the fluxes is very much the same as for F_WOODY_LITTER. Again the "FF_non woody litter" flux is declared above. Parameters $b^{foliage}$ and δ^{nwl} have the same functionality then in the equations of woody litter decay fluxes. There are is harvest efficiency factor, due to the fact that all foliage remains entirely in the forest ecosystem.

The soil system of the {FOREST} module receives carbon input via three different entries. Non woody litter from foliage and woody litter from small branches shed to the ground enter the litter compartments constantly. Forest damage that leads to natural losses without use of the timber is completely moved into the soil system. The third source of carbon to the soil system is accompanied by the harvest events, which leave the unexploitable parts (foliage, roots, most of small branches) on the forest flour.

The litter pools F_WOODY LITTER and F_NON WOODY LITTER have connections to the mineral soil pools F_ACTIVE MINERAL SOIL and F_STABILIZED MINERAL SOIL since the decay of the litter carbon flows partially into the latter pools.

F_ACTIVE MINERAL SOIL

The pool of active mineral soil carbon is the last station in the cycle of the leaf/needle material within the system boundaries. It underlies a specific respiration setting free CO_2 to the atmosphere resulting in the flow of "FF_active mineral soil respiration" leading into the "F_respiration" dispatcher. In addition this compartment is the address of carbon flows resulting from “AF_land use change”, where the soil carbon of agricultural soil compartments is transferred into the {FOREST} module.

The balance of the active mineral soil pool is given by the following equation (25):

$$\begin{aligned} F\_ACTIVE\_MIN\_SOIL = F\_ACTIVE\_MIN\_SOIL \\ + FF\_non\_woody\_litter\_decay \\ + AF\_land\_use\_change \\ - FF\_act\_min\,eral\_soil\_respiration \end{aligned} \tag{25}$$

“FF_non woody litter decay” has been described under F_NON_WOODY_LITTER section. The remaining fluxes are calculated in detail as follows:

$$FF\_active\_min\,eral\_soil\_respiration = \delta^{asr} \cdot F\_ACT\_MIN\_SOIL \tag{26}$$

“AF_land use change”: is just the transfer of the soil carbon content of those areas that are shifted to afforestation from within the {AGRO} module. See there for detailed calculation.

F_STABILIZED MINERAL SOIL

The stabilized mineral soil carbon pool represents the carbon pool of the longest residence time. It is filled up by the fraction of the woody litter decomposition fluxes not directly respired (“FF_woody litter decay”). Also the woody slash fraction of harvest enters this pool. It underlies respiration triggered by a small respiration constant, and is by far the largest soil carbon pool of the entire {FOREST} module. Carbon losses due to erosion

The balance of the F_STABILIZED MINERAL SOIL pool looks like (equation (27)):

$$\begin{aligned} F\_STABILIZED\_MIN\_SOIL = F\_STABILIZED\_MIN\_SOIL \\ + FF\_woody\_litter\_decay \\ - FF\_stabilized\_min\,eral\_soil\_respiration \\ - FA\_soil\_erosion \end{aligned} \tag{27}$$

Most fluxes have been explained in detail in above sections. Only the link to the {AGRO} is special. “FA_soil erosion” is the carbon transferred to {AGRO} due to leaching effects. It is calculated to be one percent of the “FF_stabilized mineral respiration”.

F_INERT MINERAL SOIL

Inert carbon stored in the defined “F_INERT MINERAL SOIL ” pool is assumed to be of a huge magnitude with an infinitely small decomposition rate (close to 0) and therefore considered to be constant over time and not taken into account within the carbon modeling.

Dispatchers

The hexagonal boxes in Figure A 4-3 represent dispatchers, meaning they are not pools but serve as points of partitioning or collecting incoming fluxes. They are virtual knots that can also found to be concatenated in the flow chart of the module. Since the F_VEGETATION pool encompasses total dentromass of the {FOREST} system, the dispatchers can also divides biomass into different parts of dentromass using the expansion factors ε^f,ε^r and ε^b, which are age class and species dependent values. The calculation of fluxes leaving the five dispatchers found in the module {FOREST} are given below:

F_harvest

The biomass of forest products expressed in MtC is always much smaller than the dentromass (again in MtC) that has to be killed in order to get the required harvest (“FP_industrial roundwood” + “FE_biomass”). The dispatcher “F_harvest” collects the “gross harvest” (in German: Vorratsabgang) divides into FP_roundwood and harvest residues “FF_harvest residues”. There are two important losses from harvested dentromass to products biomass. First, all parts included in the expansion factors are unexploitable in terms of roundwood production. Secondly, a fraction β of the potentially exploitable roundwood is lost due to partial harvest processing efficiency.

This dispatcher collects all fluxes of harvested dentromass (including roots, branches, foliage etc.):

$$F\_harvest = FF\_final\_cutting + FF\_thinning + FF\_calamities \tag{28}$$

Calculation of “FF_roundwood” uses the expansion factors (1 $-\varepsilon^f-\varepsilon^r-\varepsilon^b$), which decreases the dentromass to the potentially harvestable biomass. “FF_roundwood” and “FF_harvest residues” are calculated as given in equations (29,30):

$$FF\_roundwood = \sum_{s=1}^{M}\sum_{k=1}^{N}\left(\beta_s \cdot (1-\varepsilon^f_{s,k}-\varepsilon^r_{s,k}-\varepsilon^b_{s,k}) \cdot a_{s,k} \cdot (Thin_{s,k} + Cala_{s.k} + m_{s,k} \cdot f\_vegetation_{s,k})\right) \tag{29}$$

$$FF\_harvest\_residues = \sum_{s=1}^{M}\sum_{k=1}^{N}\left((1-\beta_s) \cdot (\varepsilon^f_{s,k}+\varepsilon^r_{s,k}+\varepsilon^b_{s,k}) \cdot a_{s,k} \cdot (Thin_{s,k} + Cala_{s.k} + m_{s,k} \cdot f\_vegetation_{s,k})\right) \tag{30}$$

the term “$m_{s,k}$ x $f\_vegetation_{s,k}$ x $a_{s,k}$” gives the amount of dentromass slashed by clear cutting.

F_harvest residues

This dispatcher has only one source: “FF_harvest residues”. This flux represents the entire biomass of those trees that have been harvested due to final fellings. thinnings, calamities or that have died for natural mortality (Natural losses). The carbon of these fluxes encompasses carbon in roots, (ε^r), leaves/needles (ε^f), small branches (ε^b) and the stem biomass ($1-\varepsilon^b-\varepsilon^f-\varepsilon^r$). Only the latter part is exploitable and the dispatcher converts it into “FF_roundwood”. But nevertheless only a fraction β of the potential harvest results in “FF_roundwood” due to losses during harvest processing.

The parameter χ indicates the fraction of slash (harvest processing losses plus small branches) which is used as “FF_chips from forest residues” (equation (31). The first equation describes the woody harvest residues leading into the F_WOODY_LITTER pool:

$$\begin{aligned} FF\_woody\_harvest\_residues = \\ (1-\chi_s) \cdot \sum_{s=1}^{M}\sum_{k=1}^{N}\left[\varepsilon^b_{s,k} \cdot \varepsilon^r_{s,k} \cdot a_{s,k} \cdot \left(Thin_{s,k} \cdot Cala_{s,k} \cdot m_{s,k} \cdot f\_vegetation_{s,k}\right)\right] \\ +(1-\chi_s) \cdot \sum_{s=1}^{M}\sum_{k=1}^{N}\left[(1-\beta_s) \cdot (1-\varepsilon^f_{s,k}-\varepsilon^r_{s,k}-\varepsilon^b_{s,k}) \cdot a_{s,k} \cdot \left(Thin_{s,k} \cdot Cala_{s,k} \cdot m_{s,k} \cdot f\_vegetation_{s,k}\right)\right] \end{aligned} \tag{31}$$

The next equation describes the foliage of the harvested and died trees representing the “FF_non woody harvest residues” flux (equation (32), going into the F_NON WOODY LITTER pool:

$$FF\_non\_woody\_harvest\_residues = (1-\chi_s)\cdot\sum_{s=1}^{M}\sum_{k=1}^{N}\left[\varepsilon^{f}_{s,k}\cdot a_{s,k}\cdot\left(Thin_{s,k}\cdot Cala_{s,k}\cdot m_{s,k}\cdot f\_vegetation_{s,k}\right)\right] \tag{32}$$

The third equation denotes the amount of carbon that can be gained as chips: “FF_chips from harvest residues” (equation (33)). This flux flows into the “F_forest products” dispatcher:

$$\begin{aligned} FF\_chips\_from\_forest\_residues = {} & \chi_s\cdot\sum_{s=1}^{M}\sum_{k=1}^{N}\left[\varepsilon^{b}_{s,k}\cdot\varepsilon^{r}_{s,k}\cdot a_{s,k}\cdot\left(Thin_{s,k}\cdot Cala_{s,k}\cdot m_{s,k}\cdot f\_vegetation_{s,k}\right)\right] \\ & +\chi_s\cdot\sum_{s=1}^{M}\sum_{k=1}^{N}\left[(1-\beta_s)\cdot(1-\varepsilon^{f}_{s,k}-\varepsilon^{r}_{s,k}-\varepsilon^{b}_{s,k})\cdot a_{s,k}\cdot\left(Thin_{s,k}\cdot Cala_{s,k}\cdot m_{s,k}\cdot f\_vegetation_{s,k}\right)\right] \end{aligned} \tag{33}$$

F_forest products

This is the last dispatcher in the harvest chain. It collects “FF_roundwood” and the “FF_chips from forest residues” chips. The dispatcher is filled up until the demand of “FE_biomass” and “FP_industrial roundwood” is satisfied. The partitioning into both fluxes is just prescribed by the ratio of “FE_biomass” (reported by {ENERGY}) and “FP_industrial roundwood” (given by {PROD}).

F_natural losses

“FF_natural losses” (equations 34,35) is the dentromass killed due to natural hazards, but in contrast to “FF_calamities” the biomass is entirely lost and can not be utilized. Therefore the dispatcher “F_natural losses” separates the woody (1 -ε^f) from the non woody parts (ε^f) of the dentromass. The corresponding fluxes are: “FF_woody natural losses”, heading into the F_WOODY LITTER pool:

$$FF\_woody\_natural\_losses = \sum_{s=1}^{M}\sum_{k=1}^{N}\left[(1-\varepsilon^{f}_{s,k})\cdot a_{s,k}\cdot NatL_{s,k}\right] \tag{34}$$

The “FF_non woody natural losses” correspondingly flows to the F_NON WOODY LITTER pool:

$$FF\_non\_woody\_natural\_losses = \sum_{s=1}^{M}\sum_{k=1}^{N}\left[\varepsilon^{f}_{s,k}\cdot a_{s,k}\cdot NatL_{s,k}\right] \tag{35}$$

A 4-2.4 Scenarios

When describing the translation of the two developed scenarios “No major changes” (NMC) and “Towards sustainability” (TS) to the {FOREST} Module it should be pointed out here, that the Austrian forestry has been and continues to be a sustainable forestry by law (Bobek et al.,1995) in the sense, that it will guarantee a relatively constant amount of timber production over time. Thus the two scenarios need a certain reformulation with respect of the {FOREST} module. Both, the NMC and TS scenario assure the aim of sustainable (long term) and constant timber production. But with respect to ecological aspects they do differ. Generally the NMC scenario tries to include all "business as usual trends" which can be observed in the Austrian forestry today. In contrast, the TS scenario tries to outline a slight trend to a more ecology oriented forestry. This means a consciously stimulated process towards the recommendations for a forestry closer to a more naturalistic management. This is also in the line with some requested answers of the customers of this study. Nevertheless it should be underlined that even the TS scenario is a realistic scenario which does not include any dramatic changes of the current forest management practices.

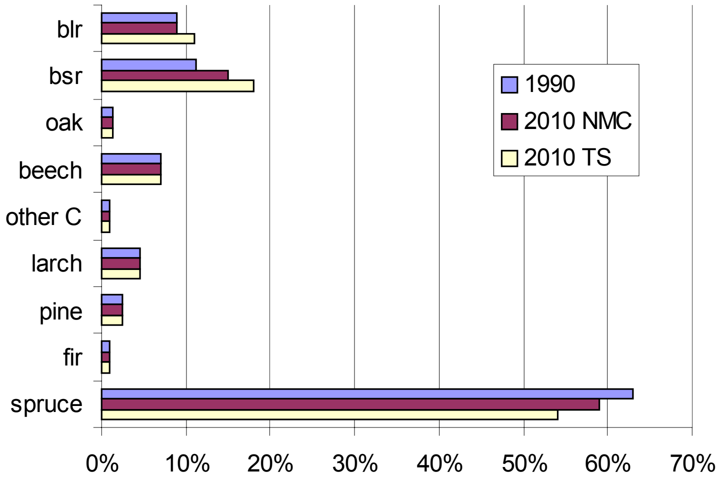
In detail the trends assumed within both scenarios translated into driving bags, driving forces and finally driving parameters are described below.

Changing to natural forest management: within the TS scenario changes of forest management are treated with two different driving parameters:

- Share of afforestation mix and
- Area to be converted to selective logging management, combined with a percentage of growing stock to be taken out to this management

Share of afforestation mix: The Austrian Forest Inventory 1992/96 reports a specific tree species composition for the first age class (1-20 years). It is assumed in the model that this composition share per tree species represents the afforestation mix within the last 20 years and is used for the replanting and regenerating of the final harvested areas. In the scenario "No major changes" this afforestation mix is maintained, for the scenario "Towards sustainability" it is assumed that the mixture of tree species in replanting and regeneration areas will turn to more broad leafed species, specifically a decrease of spruce and increase of non coniferous species (bsr and blr). Figure A 4-4 shows the assumed afforestation mix of tree species in 1990 and for the scenarios in the year 2010, where the assumed shares change continuously between 1990 and 2010. In the model this calculations are driven by tree species specific parameters (DPF_Share of afforestation species).

Figure A 4-4: Changes of tree species composition in the year 1990 and in both scenarios over time



Selective logging management: Due to the structure and concept of the FOREST module it should be pointed out that a modeling of selective forest management is not within the scope of this study. To indicate possible consequences for a change from uniform high forests into selective logging management a strategy of *Hanewinkel (1998)* is observed. Therefore the first steps of such a possible conversion are simulated. Potential forest area for such transformation strategies can be defined as secondary coniferous stands on climax forest stands (e.g. Abietum or Abieti Fagetum). *Hanewinkel (1998)* proposes a so called “direct” transformation of even aged stands in age class 2 by harvesting parts of the growing stock in form of small gaps, where regeneration can take place. On the basis of the Austrian Forest Inventory *Prskawetz et al. (2000)* found out that the area of secondary coniferous stands, in particular pure Norway spruce stands on Abieti Fagetum sites is around 280.000 ha, where 35% (98.000 ha) of the growing stock refers to the second age class. This area represents the amount for a possible conversion. In the scenario “Towards sustainability” it is assumed that each year beginning in 2000 5% of this potential area are converted. It is assumed in the model that 20% of the growing stock in age class 2 have to be taken out for transformation reasons. The conversion is driven by the defined „DFP_Area to be converted to selective logging management“ and „DFP_% of growing stock to be taken out to this management“.

Losses of exploitable forest: in the year 1994 (Frank, 1995) the total area of “forest nature reserves” - forests determined to have a natural development of the forest ecosystem over time - where no human disturbances occur, was 3.224 ha (0.08% of the total forest area in Austria). Between 1990 and 1994 this area increased from 2.342 ha to the amount 1994, which means an annual increment of around 220 ha. In the scenario “No major changes” this amount is assumed to remain on this level, for the scenario “Towards sustainability” an increase up to 300 ha per year is assumed to be converted from exploitable forest to “forest nature reserves”. Thus the share of unexploitable forest change to primeval forests follows a trend of 0.01% of the exploitable forest area / year. In the model this change is driven by the parameter “DPF_Changing from exploitable to unexploitable forests”.

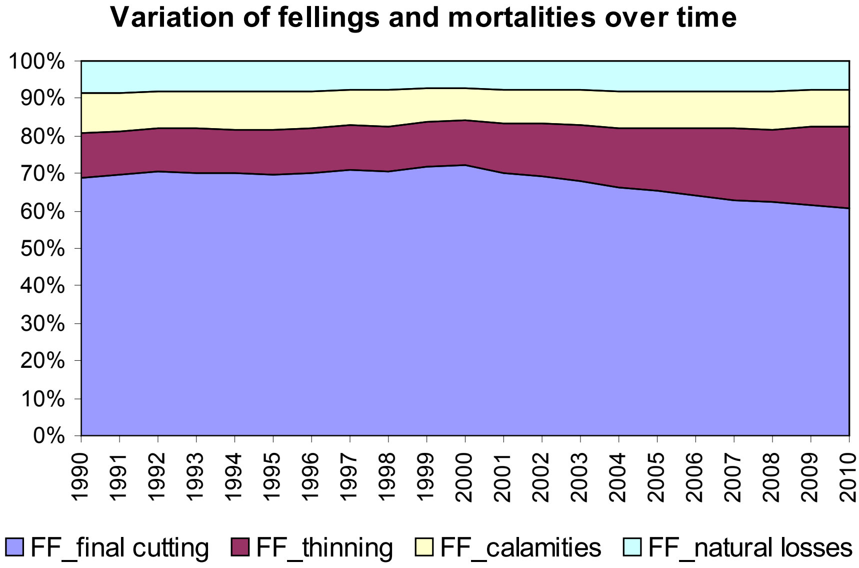
Changes in management practices: in addition to the driving forces described above two further management impacts on the forest carbon balance can be modeled:

- Increase of harvest residues utilization
- Changing rate of thinning

Increase of harvest residues utilization: harvesting of timber leads to the an unavoidable slash production expressed as the parameter β (see Table A 4-2). On the one hand this produced slash is represented by small stems, branches and foliage, on the other hand side some stemwood losses occur when transforming m³ of standing stock o.b. into m³ of roundwood u.b.. *Rieder (2000*) found out that these transformation losses for the exploitable forest is 25%, where the bark fraction (conversion of m³ o.b. to m³ u.b.) is 10%. *Böswald (1996)* reports harvest losses between 0.79 and 0.85, depending on the tree species. In the model this amount of produced harvest residues is given by the flux “FF_harvest residues” leading into the dispatcher “F_forest residues”. Parts of the calculated harvest residues are meant to remain on forest ground leading into both litter pools, parts are assumed to be used as chips for energy generation (“FF_chips from forest residues”). For the scenario “No major changes” the dispatcher “F_forest residues” of both fluxes is tuned in a way, that the amount of 425.000 m³ of chips from forest residues are leaving the forest system as product into the energy module *(Bittermann et al.,1995; Schmidt,1994).* Following the calculations this means an effective harvest residue utilization of 10%. In the “Towards sustainability” scenario this amount is assumed to increase up to the double value until 2010. This leads to a lower fuelwood harvesting of the growing stock, but also to lower inputs of woody debris into both forest litter pools.

Changing rate of thinning: The Austrian Forest Inventory reports data of forest harvesting by providing values of decreases of the growing stock distributed into natural losses (remaining on forest ground) calamities, thinning and final felling. Inventory data of 1992/96 are used for the "No major changes" scenario. In the "Towards sustainability " scenario the share of natural losses and calamities is assumed to remain on the same level, but the thinning rate in comparison to the final cutting rate is changing over time (see Figure A 4-5). Therefore it is assumed that the initial thinning rate increases up to 22% (1% per year), combined with a decrease of final felling by 10% in the year 2010.

Figure A 4-5: Distribution of fellings and mortalities for the "Towards sustainability" scenario



A 4-2.5 Model Formulation

Program Details and VBA Programming

The here presented details of the {FOREST} module are more of technical nature; and mainly concern with the coupling to the other modules within the ACBM. Internal {FOREST} source code formulation are discussed here because they should easily be derived from the mathematical model formulation given in A 4-2.3. Only in some cases, where programming as a technique influences model behavior, this information is given under the next section.

Program Details

Subsequently calculation of harvest as demanded by the modules {PROD} and {ENERGY} is described, followed by some remarks on the initialization of the soil system within {FOREST}.

Coupling with other ACBM modules

Among all ACBM modules, the {FOREST} is the module, that is the most dependent from the output of the others. In this sense it is a “reactive” module, because it is addicted to the requirements of {PROD} and {ENERGY}.

The module {PROD} sets a roundwood demand via the INPUT_OUTPUT list, which is directly in units of MtC. In contrast, {ENERGY} demands fuelwood expressed in PJ. Therefore the first internal step is to recalculate PJ into the amount of wood related to energy by the given heating value. Afterwards roundwood and fuelwood demand are added to result in the total roundwood (still expressed in MtC) needed to be supplied. Internally the ratio fuelwood/roundwood is stored, but the harvest function does not differ between harvest for roundwood supply or fuelwood logging. There is only one exception because the wood coming from non forest floors entirely goes into fuelwood production and is first subtracted from the fuelwood demand that has to be taken out of the forest.

The wood demand comes in wood production, meaning that all losses and the wood referring to the expansion factor have to be added in order to get the amount of standing stock that has to be harvested. The ratio of wood production over fellings in terms of standing stock losses varies around 0.45; it is not a constant ratio because harvest composition in age classes can change slightly from year to year. When production demand is determined, it is partitioned on tree species using fixed factors taken from the 1990 situation reported by the forest inventory.

As noted in Appendix A 4-2.3, adaptation of parameters in the harvest function serves to fit the clear cut area in every annual time step, but this determines only the amount of wood harvested due to clear cut. Other sources of harvest are thinning, slash use and calamity use that allow for a use of the felled trees. Since calamities can not be directly managed and since thinning is assumed to follow prescribed regimes, the model has to consider the amount of harvest resulting from the latter two independently from the demand for wood production. This crude assumption (crude only in the case of thinnings) allows for an initial calculation of harvest resulting from thinning and calamities which are then subtracted from the demand, leaving the rest as demand for clear cut production.

To determine the area that has to be clear cut in order to meet this demand parameter A_s in the harvest function (see equation (17)) is altered stepwise using a bracketing bisectioning algorithm. It is not possible to calculate the area analytically because standing stock over age classes is not such a function. The algorithm is a run-time saving approach which may calculate clear cut areas up to any exactness required. However, the smaller the difference between demanded and the supplied harvest fluxes (FE_biomass and FP_roundwood) should be, the longer calculates the algorithm. After some studies of this relation, 5% absolute deviation from the demand were found to be a good compromise between exactness and time saving.

The so determined amount of “gross harvest” flows through the dispatchers as depicted in Figure A 4-3 and described in chapter A 4-2.3 in sufficient detail.

Soil system equilibrium calculation

The soil system within the model starts with initial values comparable to the literature (see Table A 4-3).

This initial equilibrium is defined trough stable soil pools under constant input of litter and harvest fluxes. These input fluxes corresponded to the 1990 starting situation with respect to age classes, stocks and harvest intensity.

Sizes of pools are prescribed by data known from the literature (*Körner et al., 1993)*, see A 4-2.2) and served as target values for the initial soil pool values. Since input fluxes are determined by the dynamics of the living vegetation, soil decay rates remained to be varied in order to archive the stable initial soil pools compatible with the literature data.

The chosen initial soil stock values where selected under two conditions: 1) over 20 simulated years, with experiencing the same input, the soil pools should differ less then 1 MtC from their initial values and 2) these initial values should lay within the scope of the above cited literature data.

VBA (BASIC) related remarks

The module {FOREST} is implemented into VBA macros using MS BASIC language. Spreadsheet cells are used only for reading input and writing model output, there are no calculations performed within spreadsheet cells.

The {FOREST} module is organized into the following Excel sheets, used for different purpose:

- Steering
- Parameters
- Data
- Large Matrix
- INPUT_OUTPUT
- Meta database
- DF_DP list (DP_DF 0, 1, 2)

The sheet „Steering“ contains the simulation relevant initial information: how many tree species included, number of age classes used within the module run, starting year and the number of time steps to perform. Additionally internal parameters to be used in the run are stored in this sheet as well. They can be changed using a graphical user interface accessible via the starting button also located here. These menu parameters can be brought back to their default values by using a reset routine, the program then copies a parameter set stored in the sheet "Parameters" to the "Steering" sheet.

The Excel sheet "Data" contains the standard input of the model like initial area distribution, initial standing stock and soil carbon. Furthermore expansion factors, increments, thinning rates and calamities are also defined here. All data within this sheet are organized within age classes of 20 years width as they could be entered manually from the forest inventory. As the "Data" sheet serves as the storage of initial values there is a related sheet called "Large Matrix", where values from "Data" are copied after interpolation into classes of one year width. In contrast to the "Data" sheet, "Large Matrix" is read and also data are written to it during the model run. Every model time step, stores new systems state variables within this sheet. Therefore the sheet "Large Matrix needs an initialization at model simulation beginning in order to confirm the correct initial state.

The sheet "Parameter" contains the backup of the sheet "Steering" and is only used for resetting tree species specific parameters to their default values.

Stepping through the time loop three further sheets are accessed: As in all ACBM modules, the "INPUT_OUTPUT" sheet serves as the linkage to the other ACBM modules; demand of roundwood and fuelwood is read as well as the annually afforested land which is passed from

{AGRO} module. These values are read before the calculation of an annual {FOREST} step, afterwards the resulting outputs as relevant for other modules are written to this sheet.

The same procedure is applied for the use of driving parameters (DP) that are defined internally according to the choosen driving force scenario. These parameters are read from the DF_DP_Liste sheets for each time step. Whereas the DF_DP_Liste2 sheet contains the scenario “Towards sustainability” parameters, the DF_DP_Liste1 sheet provides parameters for the “No mayor changes” scenario. There is another set kept in the DF_DP_Liste0 sheet which is a dummy scenario, only for internal use which does not set any trends but keeps driving parameters on their 1990 values. These data are not used within the ACBM simulations. Finally, all important module output, that is required by any means of the ACBM (like FCA, IPCC etc.) is written to the “Meta database” sheet when proceeding.

The reading and writing to the above defined Excel sheets is performed by running the module {FOREST} which has to perform the following steps:

1. READING input and control variables

2. INITIALIZATION and INTERPOLATION of variables

3. PROPAGATION of age classes and CALCULATION of fluxes for each time step

The process is described as follows:

First, ACBM main calls the initialization module “init” which does steps 1 and 2 of the above list. The main afford of reading control variables is to provide all {FOREST} macro routines with the necessary run control variables, e.g. which DF_DP scenario is to be run, which initial data set is to be used etc. . Initialization is a very important routine to get the right initial states of the system. It sets back all system variables, age classes etc. to the starting values corresponding to the year 1990. This is done by the macro module ”initialize”.

Then control is given back to the ACBM main module, which organizes the time loop trough the different modules. As it comes to {FOREST}, a routine “propagate_step” is executed for every simulated time step or model year. Within this routine all important annual calculations are executed, accompanied by reading and writing the above described Excel sheets. Following bullet points presents the names of the macro routines corresponding to the steps mentioned and described above:

- Initialize: this macro is called once before a model simulation run in order to ensure the right starting values of standing stock, area and soil carbon. The values are then set to the 1990 conditions. This routine also organizes and distributes the correct simulation run parameters, the references to the DF_DP set, the internal parameters and sets fluxes to zero.

- Interpolate: Since age class related information of the inventory is given in classes of 20 years width they have to be interpolated into classes of one year width in order to match the time step of the simulation.

- Propagate_step: Performs one annual step reading input from other modules through the INPUT_OUTPUT sheet. Driving parameters are read from the corresponding DP_DF data sheet. Results are written to the INPUT_OUTPUT sheet as well as into the “Meta database” sheet.

A 4-3 Results

A 4-3.1 Dynamic model behavior

In Figure A 4-12 and Figure A 4-16 the results of the {FOREST} module refer to the terms of NPP (net primary production), NEP (net ecosystem production) and NBP (net biome production). Plant respiration equal to a release of CO_2 to the atmosphere, reduces the GPP (gross primary production) leading to the NPP and resulting in a short term carbon uptake of a forest ecosystem (see Figure A 4-6). This flux is equal to the module "TF_net primary production". Subtracting the amount of heterotrophic respiration – given by the flux "FT_heterotrophic respiration", equal to the decomposition of organic carbon in dead organic matter and soil pools), additional CO_2 is emitted to the atmosphere, providing the amount of NEP. This term represents the mid term carbon storage of a forest ecosystem. Finally, the net biome production (NBP) can be derived by subtracting the anthropogenic and natural disturbances (harvest, forest clearance, fire etc.) *(Schulze and Heimann, 1998).* Those fluxes are represented by the "FF_final cutting", "FF_thinning", and "FF_calamities". This NBP is appropriate for the net carbon balance of a specific area.

Figure A 4-6: Overview of the most important terms of terrestrial carbon uptakes (adapted from *Steffen et al. (1998) in IPCC (2000))*

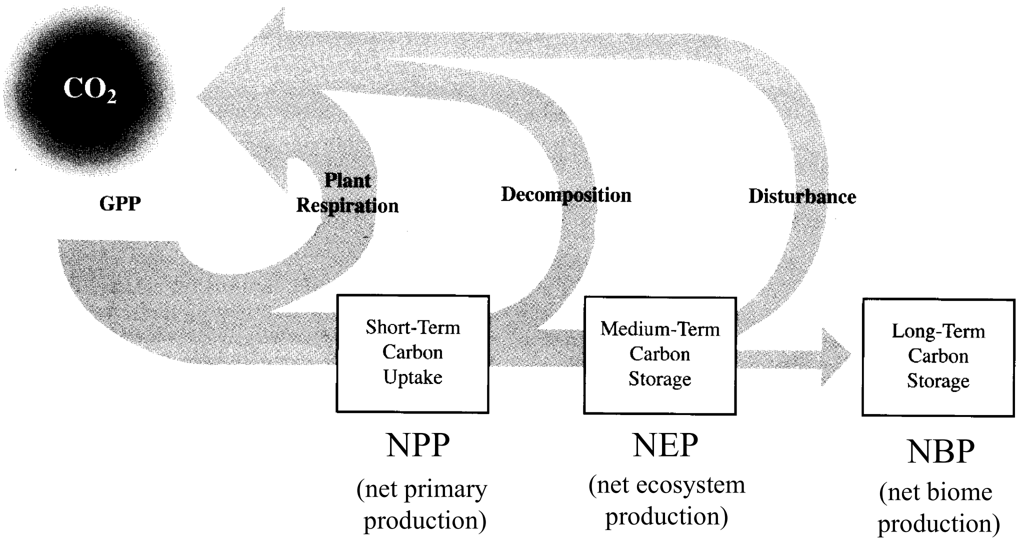


Figure A 4-7: Variation of the most imported carbon pools within the {FOREST} module over time, here calculated for the NMC scenario.

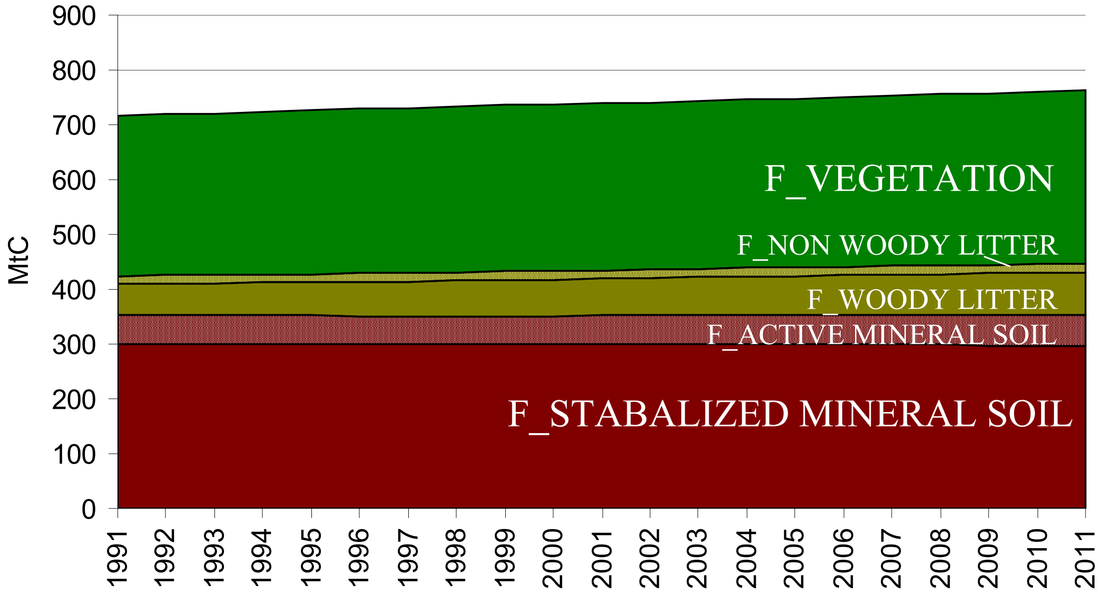
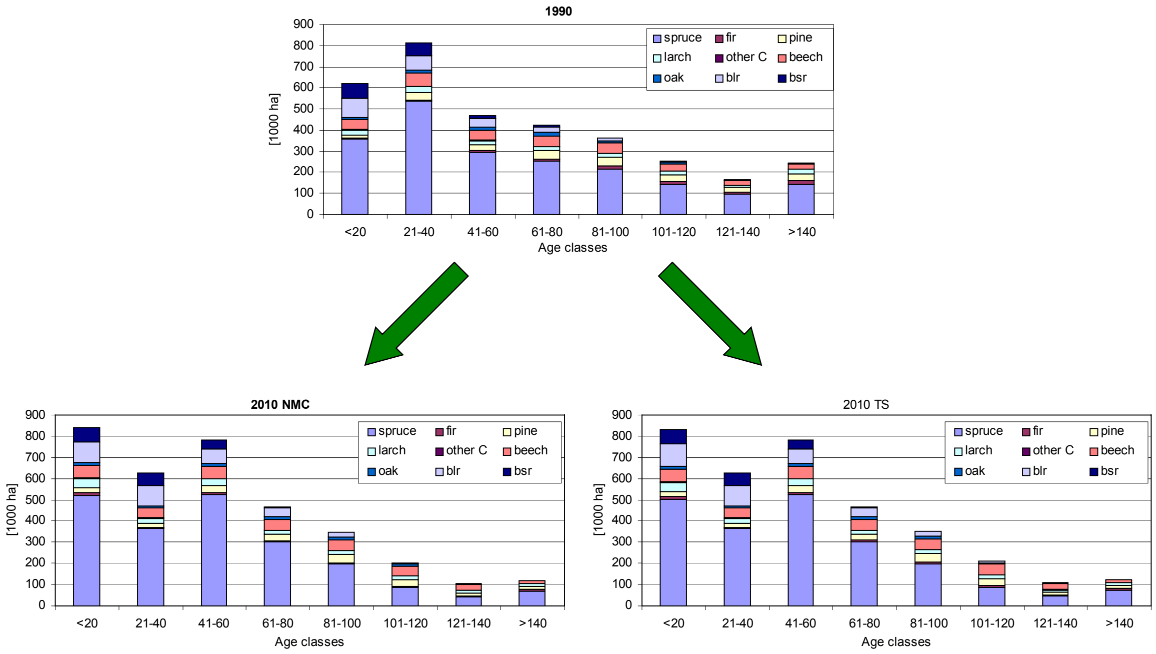


Figure A 4-7 shows the development of the defined carbon stocks of the Austrian exploitable forest. Carbon stocks in the C-pool of F_STABILIZED MINERAL SOIL and F_ACTIVE MINERAL SOIL remains constant over time. On the basis of an initial average, age class weighted carbon storage in the exploitable forest soil system in 1990 (Table A 4-3), the total modeled average amount of carbon stored in the forest soil system is around 337 MtC, representing an average stock of 101 t per ha . C storage of dead organic matter pools represented by both, F_WOODY LITTER and F_NON WOODY LITTER remain constant as well, with a small increase of the woody fractions over time. As an average amount between 1990 and 2010 some 82.5 MtC are reported, resulting into 420 MtC for the entire soil system of the exploitable forest. For comparison, due to the amount of NPP and forest harvesting regimes the F_VEGETATION pool increases from 290 MtC to 329 MtC (NMC scenario) and 325 MtC (TS scenario). Following the harvest regimes defined in both scenarios, the age class distribution of the year 1990 will change to a new distribution depicted in Figure A 4-8. The differences between the NMC and TS scenario refers to the different afforestation mixture and the different balances of thinning and final cutting regimes assumed.

Figure A 4-8: Development of the age class distribution referring to the area for both scenarios in 1990 and 2010.



Harvest regimes and area transfer from agricultural land result to an area of the first age class (1-20 years) of more than 800 000 ha in both scenarios. Due to natural management the area of spruce in the first age class, substituted by “blr” and “bsr” tree species (compare with Figure A 4-4)is smaller for the TS scenario.

A 4-3.2 Scenario: No major changes

Figure A 4-9 and Figure A 4-10 show the development of flows out and into of the {FOREST} module. It is apparent that there are major changes over the modeling period for the NMC scenario. The marked peak of the flow from the {FOREST} to the {ENERGY} module is a direct result of a high fuelwood demand required in the year 2000. This indicates the high influence of the biomass use (fuelwood and chips from forest residues) on this carbon flow in comparison to the amount of bark delivered by the {PROD} module from sawnwood production. However, the flow is very sensitive to the total carbon flow change out of the forest in comparison to the initial amount of 1990. It should be mentioned at this point that within both figures changes with respect to the initial amounts of 1990 are depicted, not providing evidence of the importance of the total absolute C-fluxes and their variation over time. It can be seen that while there is an increase in the years from 1990-2000, this trend reverses during the ongoing 10 years. This behavior can be explained by the fact that an increasing demand of industrial roundwood production (from {FOREST} to {PROD}), combined with an increasing amount of bark and sawdust for energy (from {PROD} to {ENERGY}). Therefore the harvest of fuelwood out of the forest is decreasing during the modeling period. For the flows to the module it is obvious that both C-fluxes increase until 2010. On the one hand this is due to an higher net primary production of the exploitable forest during the next year mainly caused by a shift of the age class distribution to younger forest stands with higher increments resulting in higher NPP rates.

On the other hand the module {AGRO} reports an increasing amount of area transferred from agricultural utilization to forest ground.

Figure A 4-9: Carbon flows from the {FOREST} module to the other modules and subsystems over time, here for the NMC scenario

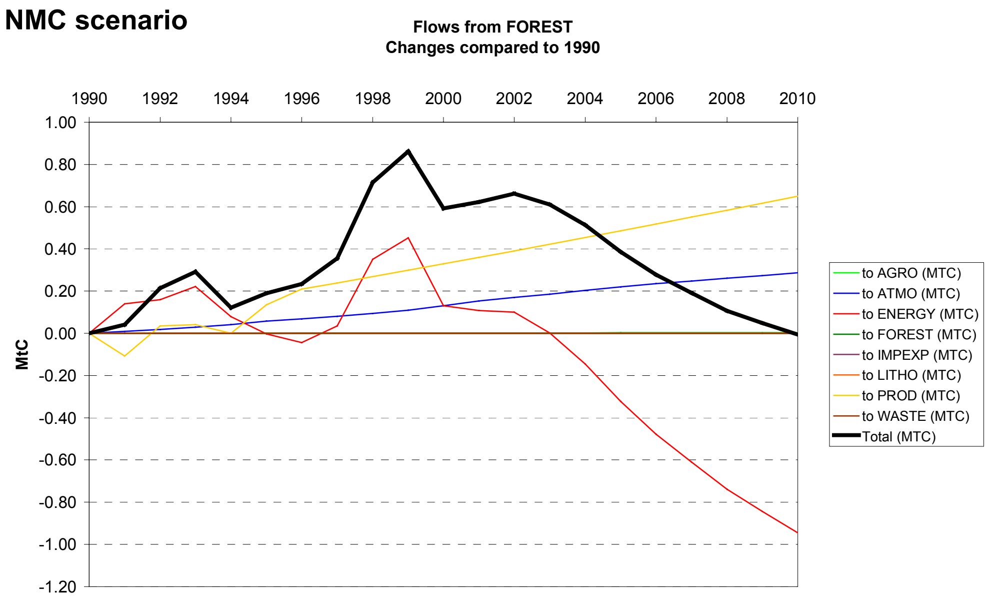


Figure A 4-10: Carbon flows to the {FOREST} module to the other modules and subsystems over time, here for the NMC scenario

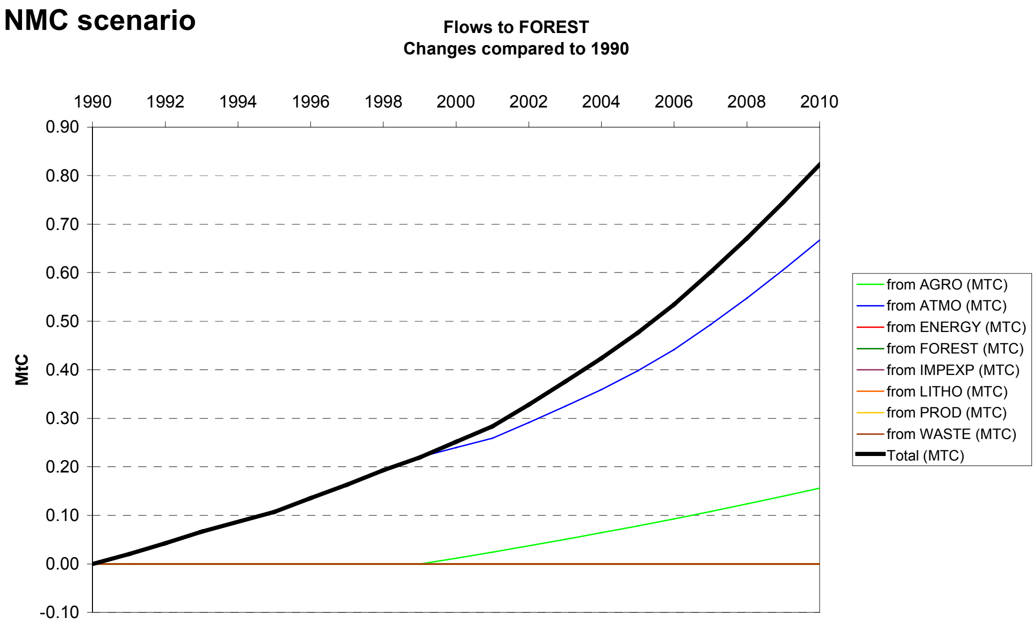
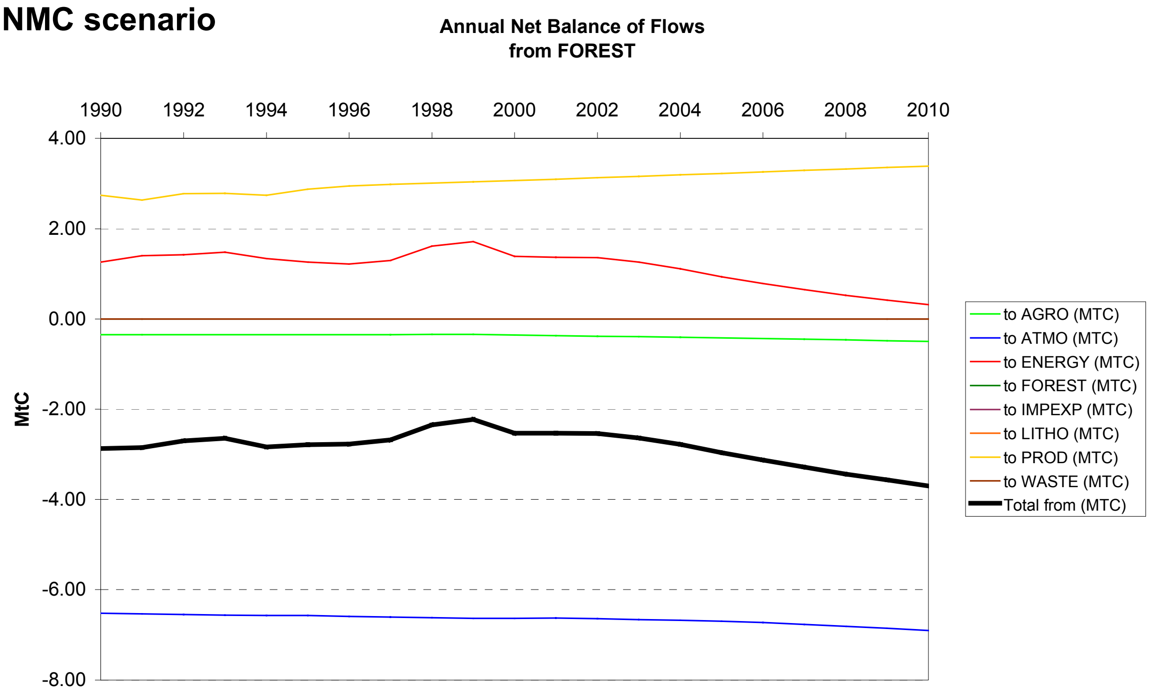


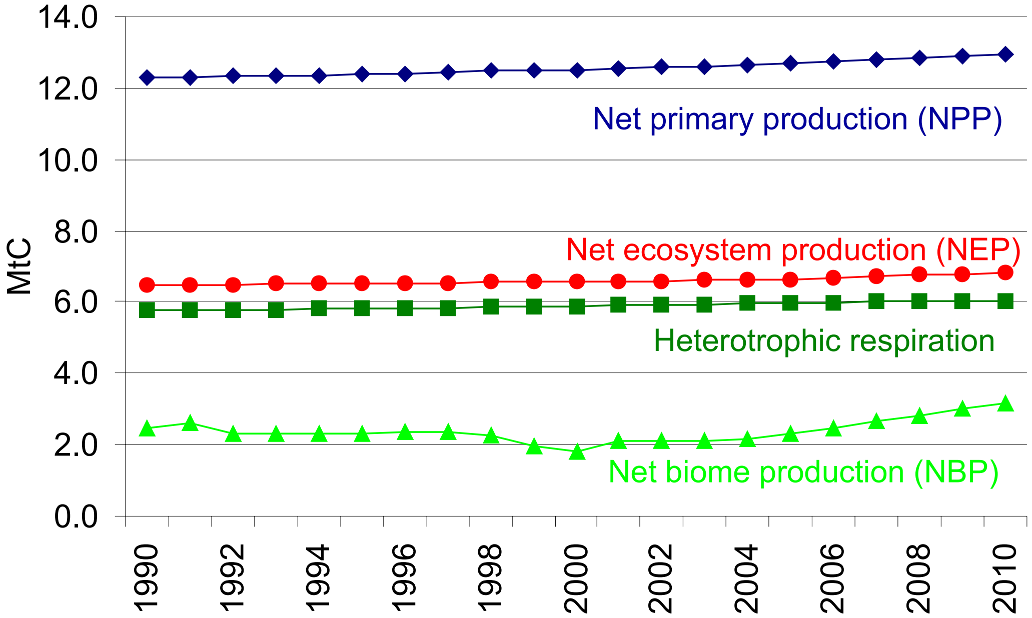
Figure A 4-11 provides an overview of the net C-balance of the {FOREST} module. Values >0 refer to a net balanced source out of the module, values <0 to net balanced sinks into the module. It can be seen that the flows out of the module (to {PROD} and {ENERGY}) and into the module (from {ATMO} and {AGRO}) lead to a total balance between –2 to –3 MtC. The blue line as the net difference between fluxes from and to the {ATMO} subsystem represents the net ecosystem production within the {FOREST} module (compare also with Figure A 4-12).

Figure A 4-11: Carbon balance of the {FOREST} module for the NMC scenario



The calculations show NPP results of 12.3 MtC/yr in 1990 increasing up to 12.9 MtC/yr. “FT_heterotrophic respiration” rates per year, also shown Figure A 4-12, remain relatively constant over time and lie between 5.8 (1990) and 6.0 (2010) MtC/yr. Comparing Figure A 4-11 with Figure A 4-12, please note that the net biome production (NBP) of the forest do not include the carbon flows from the {AGRO} module due to land use change. In Figure A 4-11 this flow is considered in the net balance of the module.

Figure A 4-12: Course of “TF_net primary production” (NPP), Net ecosystem production (NEP), Net biome production (NBP) and the “FT_heterotrophic respiration” over time as a result of the {FOREST} module modeling for the scenario NMC.

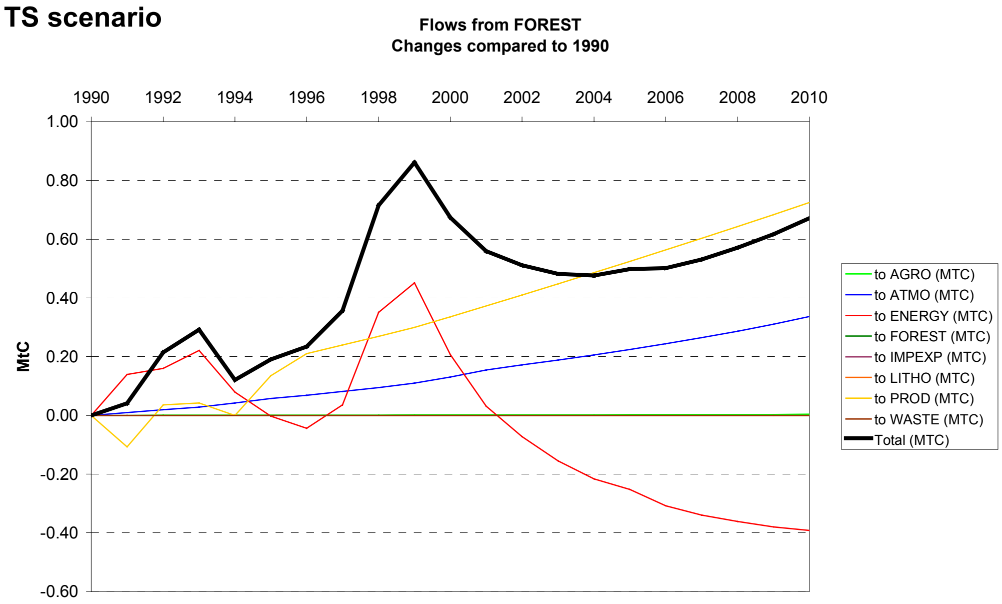


As a result, the net ecosystem production (NEP) therefore is given by 6.5-6.9 MtC/yr. Following the model results, the course of the NBP, representing the amount of total sink strength of the exploitable forest, is varying around 2.0 Mio tC / year. The lowest sink is provided for the year 2000 (1.8 MtC/yr), the highest sink strength is expected for the year 2010 (3.1 MtC/yr).

A 4-3.3 Scenario: Towards sustainability

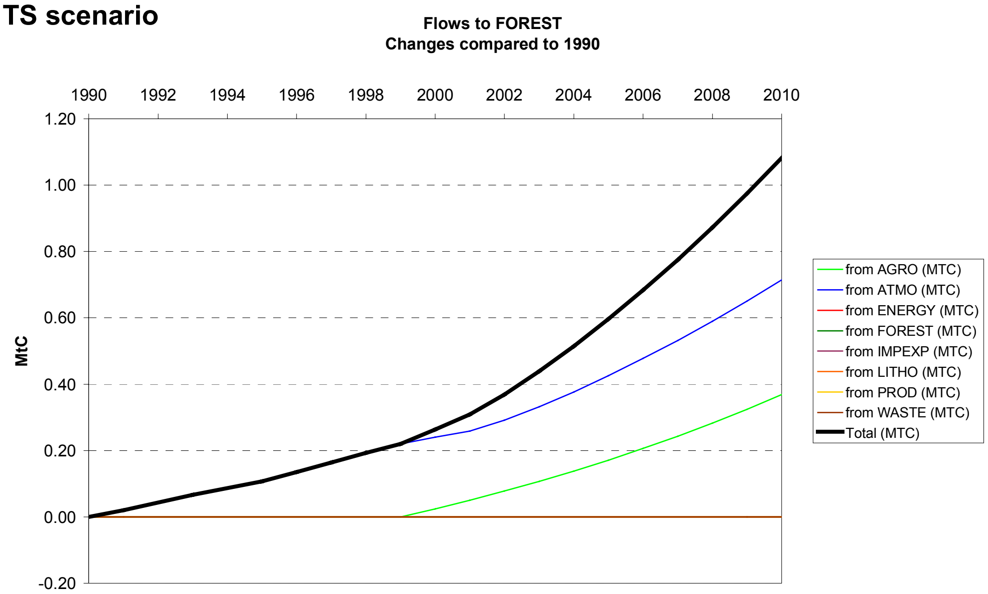
In comparison to the NMS scenario the carbon flows from the {FOREST} module to the other modules and subsystems differ significantly. In spite of an higher increasing industrial roundwood production (flow from {FOREST} to {PROD}) combined with an higher delivery of biomass (bark, wood processing residues) for energy ({PROD} to {ENERGY}), a lower decrease of the fuelwood production for the TS scenario (from {FOREST} to {ENERGY}) is shown in Figure A 4-13, mainly influenced by the driving force of “Energy & Fuel Mix” in the driving bag “Economic Structural Changes” within the {ENERGY} module. The more industrial roundwood is required by {PROD} module, the higher the amount of biomass is delivered to the {ENERGY} module, leading to a decrease of fuelwood harvest in the {FOREST} module. This indicates the high influence of the fuel use within the energy sector on the carbon flow out of the forest. Following the increasing amount of harvested industrial roundwood ({FOREST} to {PROD}) a maintaining fuelwood use in the line of the amount in 1990 will decrease the net carbon balance of the {FOREST} module for this scenario in a significant way.

Figure A 4-13: Carbon flows from the {FOREST} module to the other modules and subsystems over time, here for the TS scenario



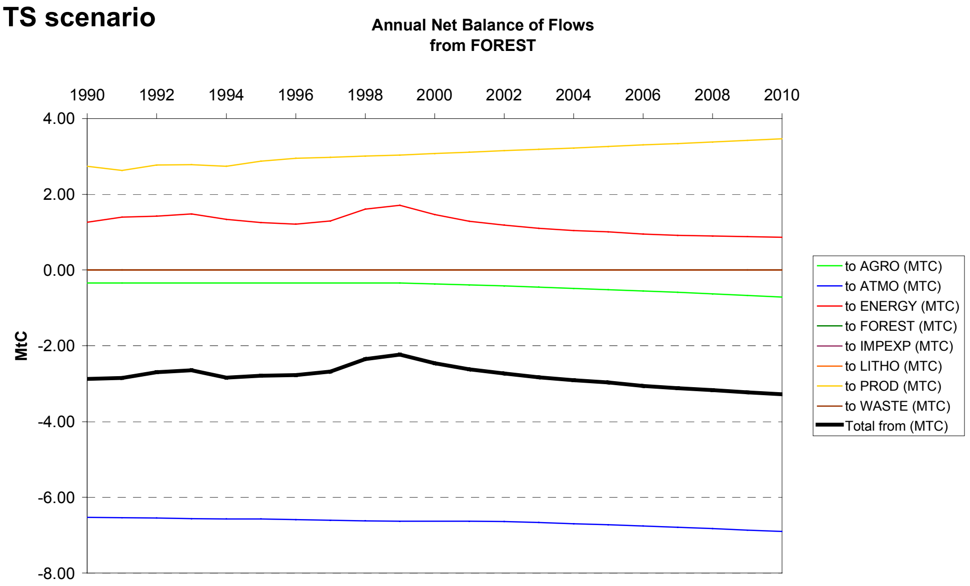
For this scenario a higher increase of the carbon sequestration (NPP) of the {FOREST} module is expected. Despite an increasing harvest regime in the TS scenario it is assumed that this is also combined with an increasing share of the thinning rate (see Figure A 4-5) combined with a higher amount of not harvested forest stands and a smaller amount of area to be afforested. In addition, compared with the NMC scenario an higher amount of areas is assumed to be transferred from {AGRO} to the {FOREST} module, influencing the NPP in a positive way. On the other hand losses of exploitable forests due to increase areas of “forest nature reserves” as well as the impacts of the assumed initial steps of forest conversion to selective logging management lead to lower NPP results over time. All influences taken into consideration, Figure A 4-14 depicts an overview of the carbon flow changes from other modules and subsystems to the {FOREST} module between 1990 and 2010.

Figure A 4-14: Carbon flows to the {FOREST} module to the other modules and subsystems over time, here for the TS scenario



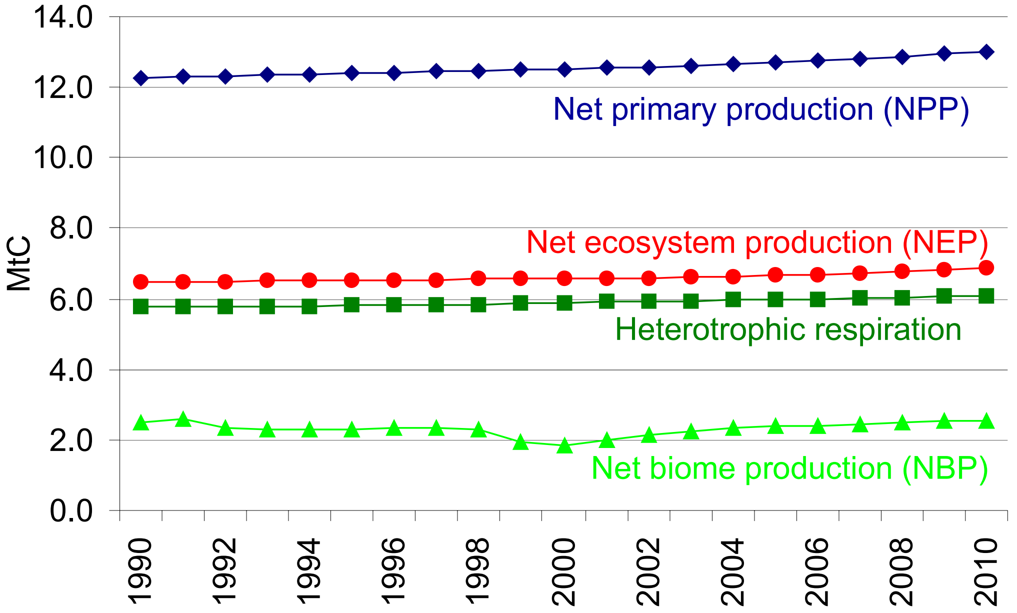
For the TS scenario Figure A 4-15 gives an overview of the net carbon flow balance of the {FOREST} module, where the flows to {PROD} and {ENERGY} represent sources and the flows from {AGRO} and ATMO} represent sinks for the {FOREST} module. Again, when comparing Figure A 4-15 with Figure A 4-16, note that the net biome production of the forest do not include the carbon flows from the {AGRO} module due to land use change (see also NMC scenario).

Figure A 4-15: Carbon balance of the {FOREST} module for the TS scenario



Compared with the results of the NMC scenario (Figure A 4-12), all fluxes also balance to total sink results between –2 to –3 MtC over the modeling period, with lower sink strength values for the last modeling year .

Figure A 4-16: Course of Net primary production (NPP), Net ecosystem production (NEP), Net biome production (NBP) and the Heterotrophic respiration over time as a result of the {FOREST} module modeling for the TS scenario.



The major influence on the carbon sequestration function of the exploitable forest is the amount of wood harvest, which within the overall ACBM model is not in the responsibility of the {FOREST} module, but is driven by the modules {ENERGY} demanding fuel wood and the needs of the {PROD} module prescribing the amount of domestic roundwood. So, if the TS scenario enhances the amount of domestically provided wood, this could easily overwrite the effects of the TS scenario defined for the {FOREST} module.

The calculations for TS scenario provide approximately the same results for the NPP (12.3 MtC/yr in 1990 to 13.0 MtC/yr in 2010). Heterotrophic carbon respiration of soil and dead organic matter to the atmosphere shows no significant differences for the TS scenario (5.8 -6.0 MtC/yr).

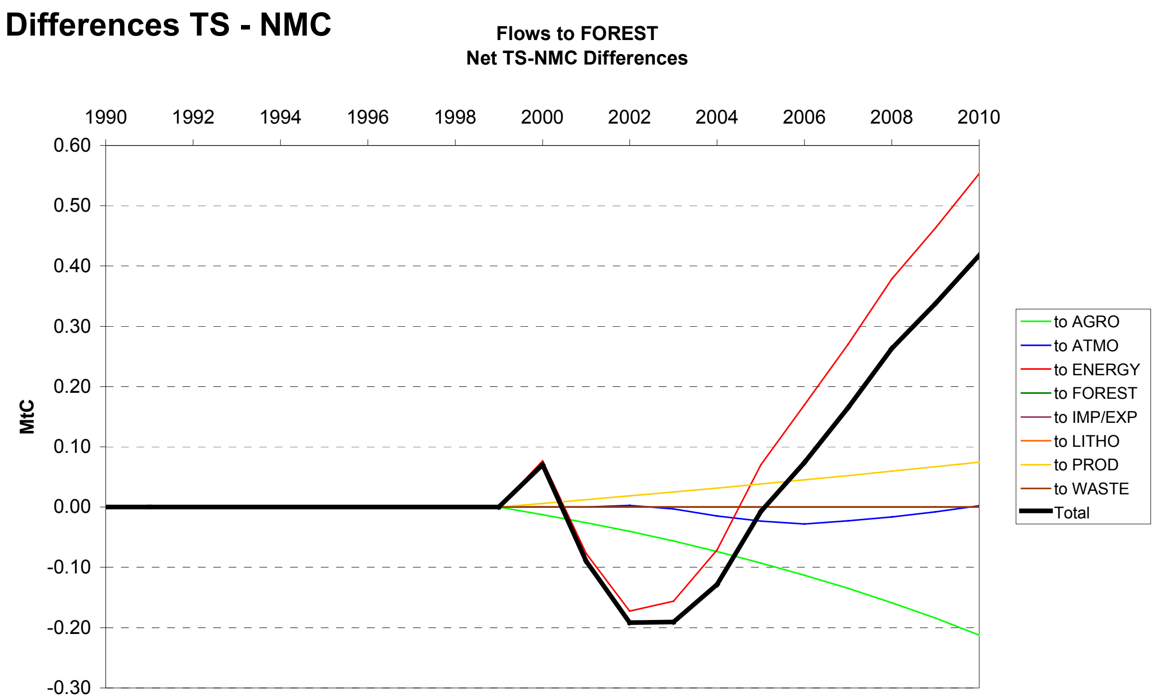
NEP results, lying between 6.5 MtC/yr (1990) and 6.9 MtC/yr (2010), are higher for the TS scenario. In comparison to the NMC scenario NBP results (see Figure A 4-16) varying between 1.8 (2000) and 2.5 MtC / year (2010).

Anticipating the results of the ACBM model runs it needs to be clarified here, that with respect to the carbon sequestration potential and carbon sink strength, both scenarios do not differ much. between both chosen scenarios.

In Figure A 4-17 the net differences between the NMC and TS scenario are given in MtC over time. The thick black line represents the difference of the net sink of the {FOREST} module between both scenarios. Between 2001 and 2006 relatively less carbon is accumulated for the

NMC scenario, but for the following time period the total C-balance changes in a way that between 2006 and 2010 a lower amount of carbon is accumulated following the TS scenario, mainly caused by the high differences between the amounts of fuelwood for energy within both scenarios. Therefore an higher net primary production of the TS scenario over time cannot compensate an higher amount of carbon leaving the system resulting into lower C-sink rate during the last modeling years.

Figure A 4-17: Net differences of the between both scenarios for the {FOREST} module



A 4-3.4 Sensitivities and Uncertainties

A 4-3.4.1 Sensitivity Analysis

The sensitivity analysis of the {FOREST} module is carried out for the most important terms of terrestrial carbon uptakes: the NEP and NBP. All parameters summarized in Table A 4-1 are varied by increasing and decreasing the values by 10 and 20 percent, where the sensitivity data are averaged throughout the period of 1990-2010. In addition, for the main input data for the model (increment, growing stock, and harvesting) , expected to be of a high influence on the model results are taken in to account for the sensitivity analysis.

It is obvious that input parameters, influencing the model results of NEP and NBP directly, are of the most significant sensitivity: increment and harvesting (Figure A 4-18). But also the variation of the initial growing stock is sensitive for the NBP results of the model. From all internal model parameters the woody litter respiration rate δ^{w}, representing the dead organic matter respiration (flow to atmosphere) and decay (flow to soil compartments) rate of the woody fraction on the forest floor.

For the results of the net ecosystem production influences of all parameters and input variables are smaller. Especially the change of harvesting remains on a low level, because within the calculation of the NEP only a changing production of forest residues influences the results with respect to harvesting. Also, the variation of increment, growing stock and parameters of δ^{w} (woody litter respiration/decay) and ε^{b} (expansion factor of small branches) are the most important influencing data for the NEP results (see Figure A 4-19).

Figure A 4-18: Sensitivity analysis of selected parameters on the Net Biome Production (NBP)

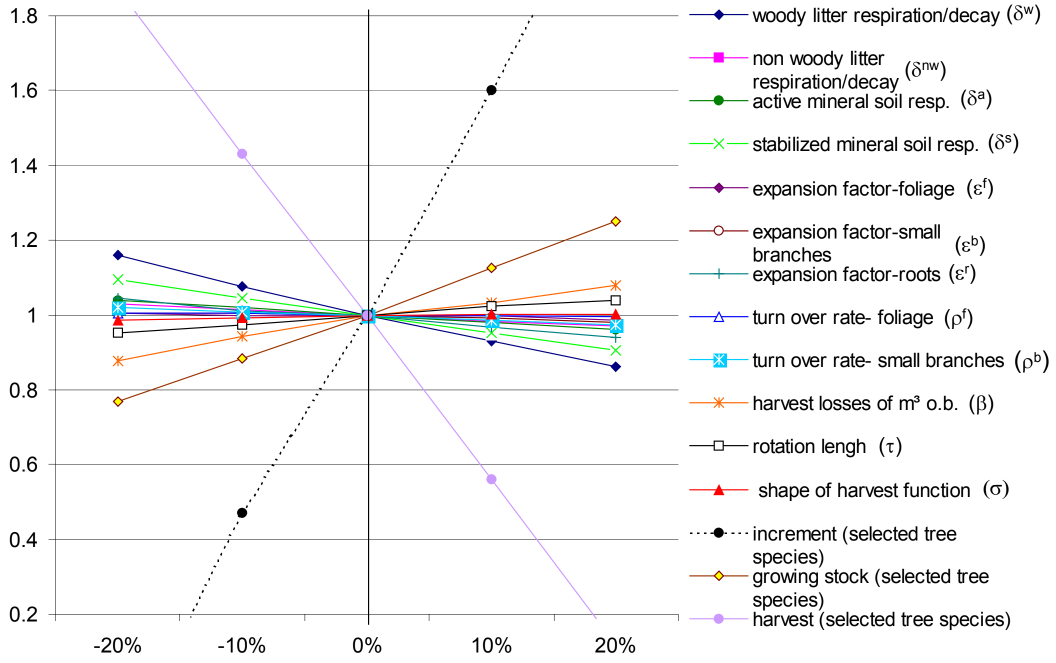
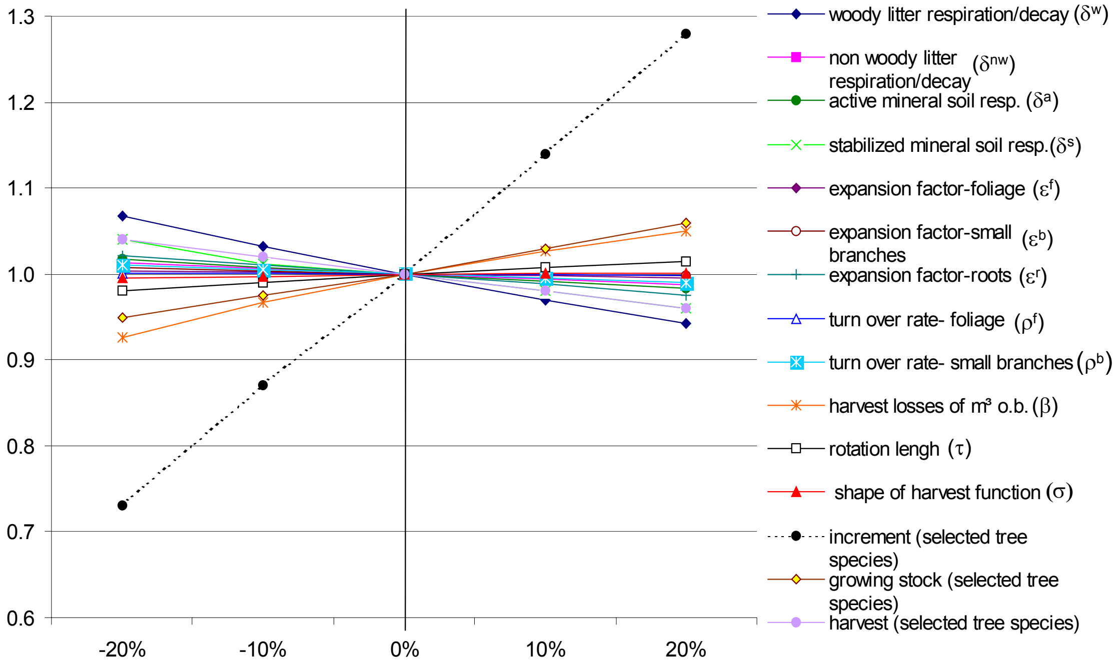


Figure A 4-19: Sensitivity analysis of selected parameters on the Net Ecosystem Production (NEP)



A 4-3.4.2 Uncertainties

Uncertainties of data regarding the F_VEGETATION pool of the {FOREST} module are provided by the Austrian Forest Inventory (see Table A 4-1). Other, referring to the forest soil and dead organic matter compartments are taken form *Körner et al. (1993).* Uncertainties of forest harvesting leading to the results of “FP_industrial roundwood” and “FE_biomass” are provided by *Jonas (2001)*. To avoid a to long calculation time of the @risk it has been decided to include only those tree species, that cover in total more than 80% of the Austrian exploitable forest. The uncertainties are defined for the following data within the {FOREST} module:

- Annual increment of the living above ground vegetation
- Growing stock of the living above ground vegetation
- Soil and litter pools
- Annual harvesting data (see chapter A5 and A8)

A 4-4 Discussion and Conclusions

A 4-4.1 Discussion

The Second National Climate Report of the Austrian Federal Government *(FMEYF, 1997)* reports a total C-sink strength of 3.6 MtC/yr, a revised sink strength of 4.5 (±1.448) MtC/yr for the exploitable forest in Austria was published by *Jonas (1997)*. Lower sink strength results of the ACBM model are mainly caused by increased forest utilization and harvesting data referring to *Jonas (2001)*. The Austrian Federal Environment Agency *(Ritter, 1999)* provides data on CO_2 emissions due to “Land use change and forestry” (“changes in forests and other woody biomass stocks") for 1980-1998 *(see also Weiss et al. 2000)*. Between 1990 and 1998 the annual net C uptake varies from 3.68 MtC (max.) and 1.47 MtC (min.), which is 13,50 Mt and 5.39 Mt CO_2 per year. Following the model results for the NMC scenario, the course of the net biome production (NBP) is varying around 2.0 MtC / year. The lowest C-sink is provided for the year 2000 (1.8 MtC/yr), the highest sink strength for the NMC scenario is expected for the year 2010 (3.1 MtC/yr). Following the current increment and harvest regimes both, the net primary production and heterotrophic respiration increase over time for both scenarios. This behavior is caused by an increasing amount of area in the younger age classes, combined with higher increments of the growing stock.

A 4-4.2 Applicability of results

Specific results of the {FOREST} module show that with respect to the Kyoto Protocol and emission targets, the forest ecosystem is able to influence a national GHG balance in both scenarios significantly. Refering to the total forest sink (NBP) for the period 1990-2010, annually between 6.6 and 11.4 Mt CO_2 are sequestered, depending on the choosen scenario. A fully consideration of these numbers - strongly depended on the level of harvesting for both, energy production and industrial utilization – in the national GHG emissions balance would decrease the results by 10.6-18.3 % compared to the amount of 1990 (62.13 Mt CO_2). Ongoing discussion and possible decisions at COP 6 to the Kyoto Protocol will show how much of this sink potential of the Austrian exploitable forest can be accounted for. However, ARD activities (Art. 3.3) in Austria influence the GHG balance slightly negative, but with respect to the national GHG balance such activities can be neglected *(Liski et al., 2000)*. Therefore, for Austria only a consideration of management activities under Article 3.4 may lead to significant sink strength changes of the forest ecosystem influencing the national GHG balance in a positive way. An increasing of timber harvest by forcing the thinning over the final felling will lead to higher sink rates of the exploitable forest. This is i) due to a higher inputs to the dead organic matter and soil pool and ii) non removing of timber out of older forest stands. Obviously, the decrease of forest stand density accorded by an enhanced increment of forest tree species after thinning activities (not modeled in the {FOREST} module) underline this statement. *Pingoud (1998)* argues that because the carbon sinks of existing forests are not counted in the Kyoto Protocol right now, there is an incentive to increase harvesting and to decrease the real net carbon balance of a country's forest. A smaller NBP under the TS scenario underlines this statement. Initializing a more naturalistic forest management may lead to disturbances in forest stands and therefore to lower C sink rates. On the other side, a change of the current afforestation mix to more non coniferous species with short rotation lengths increases the current increment and therefore NPP. A conversion of areas to selective logging management leads to a lower sink rate within the modeling period. Losses of forest areas to forest nature reserves decrease to carbon stock of the exploitable forest in addition. Higher carbon sequestration can be achieved when increasing the use of harvest residues, because an increased amount of chips from forest ground instead of standing biomass (fuelwood) combined with ongoing increments in the following years are used for energy instead.

A 4-4.3 Priorities for future work

For future calculation carbon accounting approaches with respect to the Kyoto Protocol - as an expression of the draft to set targets for reducing the Greenhouse house gas (GHG) emissions by United Nations Framework Convention on Climate change (UNFCCC) - will be of interest for the decision maker. It allows Annex I countries to incorporate activities in the Land Use, Land Use Change and Forestry (LULUCF) sector in meeting targets for limiting GHG emissions. Austrias target within the EU-bubble of reducing its GHG emissions by 8 % is rather high with – 13%. Within the field of LULUCF the Kyoto Protocol recognizes not only GHG emission reductions, but also the removing of GHG can be taken into account to achieve the quantified targets. For the first commitment period between 2008 and 2012 LULUCF direct human-induced activities like afforestation, reforestation and deforestation (ARD) (Art.3.3) and additional human induced activities (Art.3.4) since 1990 can be taken into account. The special report on LULUCF, published for the Intergovernmental Panel on Climate Change *(IPCC, 2000)*, examines the scientific and technical state of understanding for different C sequestration strategies and relevant articles of the Kyoto Protocol. For Art. 3.3. *Liski et al. (2000)* found out that this article is irrelevant for countries like Austria, where the carbon sink of trees is large. For future calculation therefore possibilities under the Art. 3.4 of the Kyoto Protocol are expected to be more relevant for Austria. However, *Weiss P. (2000)* calculated a projected carbon stock change over the first commitment period on land afforested, reforested and deforested since 1990 up to 2012 by 1.877 MtC, which is annual uptake of 0.375 t C/yr. By contrast to this amount some 2.9 MtC (0.580 MtC/yr) for the commitment period have to be subtracted due to deforestation activities. Therefore including ARD activities in the accounting approach for Austria, a net source of carbon (-0.205 MtC) has to be taken into consideration. Regarding Art. 3.4 (additional human induced activities) it has to be decided which activities, if any, will be accepted and determined by the meeting of the parties to the Protocol. An ongoing discussion about this topic is done by *(Schlamadinger et al., (2000)*.

It has been decided at this stage, that no additional programming of the {FOREST} module will be carried out until final decisions are made at COP 6 in Den Haag, November 2000. At the moment there are several opportunities to reduce the rate of build-up of atmospheric CO_2 emissions through management activities in the field of Land Use, Land Use Change and Forestry (LULUCF). For further calculations accounting approaches with respect to the decisions of COP 6 should be included in the {FOREST} module.

Hasenauer et al. (1999) found out that between the period of 1961 and 1990 the diameter increment obtained from cores of Norway spruce across Austria have increased significantly. This indicates that a biogeochemical modeling using mechanistic ecosystem models *(Running and Coughlan (1988),* may lead to different results of NPP including the possible influences of climate change, water availability and temperature. Therefore, for future calculations a comparison with biogeochemical modeling (mechanistic models) with age class models like the ACBM {FOREST} module or CaBProM (Carbon Balance Budget Model, *Böswald and Wierling (1995), Böswald (1996)) should* be carried out to elaborate the advantages of both modeling approaches.

A 4-5 References

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A 4-6 Annex

Table A 4 Annex 1: List of internal, not age class dependent parameters used within the {FOREST} model (see also Table A 4-2) for different tree species.

	τ [yr]	σ [-]	χ [%]	β [%]	f^d [kg/m³]	f^c[-]	LHV[MJ/kg]	ρ^f[1/yr]
Spruce	90.0	0.080	0.100	0.85	379.0	0.503	19.0	0.09
Fir	85.0	0.080	0.100	0.85	363.0	0.504	19.0	0.09
Pine	115.0	0.090	0.100	0.85	431.0	0.502	19.0	0.18
Larch	120.0	0.099	0.100	0.85	487.0	0.496	19.0	1.00
Other C	80.0	0.025	0.100	0.85	414.0	0.501	19.0	0.12
Beech	140.0	0.066	0.100	0.85	558.0	0.490	19.0	1.00
Oak	150.0	0.033	0.100	0.85	571.0	0.502	19.0	1.00
B l r.	110.0	0.055	0.100	0.85	585.0	0.492	19.0	1.00
B s r.	55.0	0.053	0.100	0.85	417.0	0.489	19.0	1.00

	ρ^b[1/yr]	δ^{nwl}[1/yr]	δ^{wl}[1/yr]	δ^{asr}[1/yr]	δ^{ssr}[1/yr]	b^{branch} [%]	b^{foil} [%]
Spruce	0.007	0.20	0.0090	0.028	0.0075	0.20	0.40
Fir	0.007	0.20	0.0090	0.028	0.0075	0.20	0.40
Pine	0.007	0.20	0.0090	0.028	0.0075	0.20	0.40
Larch	0.007	0.20	0.0090	0.028	0.0075	0.20	0.40
Other C	0.007	0.20	0.0090	0.028	0.0075	0.20	0.40
Beech	0.007	0.20	0.0090	0.028	0.0075	0.20	0.40
Oak	0.007	0.20	0.0090	0.028	0.0075	0.20	0.40
B l r.	0.007	0.20	0.0090	0.028	0.0075	0.20	0.40
B s r.	0.007	0.20	0.0090	0.028	0.0075	0.20	0.40

Table A 4 Annex 2: Used values for the term ε^r (see also Table A4-2) for different tree species and age classes *(Körner et al.,1993)*

	I	II	III	IV	V	VI	VII	VIII
Spruce	0.110	0.200	0.220	0.220	0.220	0.220	0.220	0.220
Fir	0.110	0.200	0.220	0.220	0.220	0.220	0.220	0.220
Pine	0.280	0.260	0.240	0.230	0.220	0.210	0.210	0.210
Larch	0.110	0.200	0.220	0.220	0.220	0.220	0.220	0.220
Other C	0.110	0.200	0.220	0.220	0.220	0.220	0.220	0.220
Beech	0.160	0.160	0.160	0.150	0.140	0.130	0.120	0.120
Oak	0.270	0.250	0.230	0.230	0.190	0.150	0.150	0.150
B l r.	0.215	0.205	0.195	0.190	0.165	0.140	0.135	0.135
B s r.	0.215	0.205	0.195	0.190	0.165	0.140	0.135	0.135

Table A 4 Annex 3: Used values for the term ε^b (see also Table A4-2) for different tree species and age classes *(Körner et al.,1993)*

	I	II	III	IV	V	VI	VII	VIII
Spruce	0.211	0.096	0.094	0.070	0.070	0.070	0.070	0.070
Fir	0.211	0.096	0.094	0.070	0.070	0.070	0.070	0.070
Pine	0.194	0.144	0.091	0.085	0.078	0.071	0.071	0.071
Larch	0.211	0.096	0.094	0.070	0.070	0.070	0.070	0.070
Other C	0.226	0.126	0.094	0.078	0.074	0.070	0.070	0.070
Beech	0.151	0.160	0.168	0.153	0.172	0.104	0.106	0.106
Oak	0.131	0.158	0.185	0.185	0.146	0.111	0.111	0.111
B l r.	0.141	0.159	0.177	0.170	0.159	0.108	0.108	0.108
B s r.	0.141	0.159	0.177	0.170	0.159	0.108	0.108	0.108

Table A4 Annex 4: Used values for the term ε^f (see also Table A4-2) for different tree species and age classes *(Körner et al.,1993)*

	I	II	III	IV	V	VI	VII	VIII
Spruce	0.185	0.112	0.094	0.055	0.055	0.055	0.055	0.055
Fir	0.185	0.112	0.094	0.055	0.055	0.055	0.055	0.055
Pine	0.058	0.052	0.046	0.031	0.023	0.016	0.016	0.016
Larch	0.037	0.022	0.019	0.011	0.011	0.011	0.011	0.011
Other C	0.128	0.084	0.070	0.043	0.039	0.035	0.035	0.035
Beech	0.034	0.025	0.017	0.016	0.011	0.010	0.009	0.009
Oak	0.029	0.023	0.015	0.014	0.013	0.012	0.012	0.012
B l r.	0.031	0.024	0.016	0.015	0.012	0.011	0.010	0.010
B s r.	0.031	0.024	0.016	0.015	0.012	0.011	0.010	0.010

Table A 4 Annex 5: Initial, corrected distribution of area (ha) for the exploitable forest per age class an tree species (compare with Table A4-2).

	I	II	III	IV	V	VI	VII	VIII
Spruce	356 466	535 729	295 254	253 717	216 553	142 224	95 222	144 410
Fir	5 465	6 558	7 651	8 745	15 303	13 117	10 931	17 489
Pine	16 521	34 010	29 638	41 662	39 476	30 731	20 893	31 824
Larch	23 079	30 731	18 707	18 707	17 614	18 707	11 056	21 986
Other C	3 279	656	44	98	273	66	0	66
Beech	43 739	63 478	48 126	50 319	49 222	36 063	22 904	24 000
Oak	10 027	12 856	14 271	15 685	11 441	5 783	1 540	1 542
B l r.	94 566	68 333	39 476	26 359	11 930	4 060	2 748	2 748
B s r.	67 815	61 183	17 410	8 125	1 493	299	0	0

Table A 4 Annex 6: Distribution of growing stock values (m³ o.b./ha) used within the model for tree species per age class.

	I	II	III	IV	V	VI	VII	VIII
Spruce	13.58	133.20	325.64	446.97	514.67	540.17	556.74	549.19
Fir	1.58	159.13	337.40	519.23	627.12	585.76	722.46	700.41
Pine	18.65	178.25	357.63	421.30	459.75	511.64	492.37	326.68
Larch	7.36	118.16	434.95	642.93	617.19	611.46	743.89	583.20
Other C	29.33	110.86	460.48	670.83	659.00	613.98	0.00	665.14
Beech	9.95	96.72	242.81	313.62	435.21	428.58	434.02	412.78
Oak	25.99	189.83	293.58	405.39	483.84	501.45	569.65	451.33
B l r.	14.79	156.87	265.64	334.02	372.91	460.35	390.89	294.64
B s r.	40.40	191.94	392.11	449.71	250.54	239.94	0.00	0.00

Table A 4 Annex 7: Distribution of increment values (m³ o.b./ha yr) used within the model for tree species per age class (calculation see chapter A4-2.2).

	I	II	III	IV	V	VI	VII	VIII
Spruce	3.24	11.73	13.75	12.14	10.22	7.67	5.44	3.65
Fir	4.59	18.27	21.64	21.03	17.59	13.29	9.53	7.36
Pine	3.92	15.18	16.83	11.78	7.53	4.63	2.77	1.94
Larch	4.52	15.42	15.58	13.46	11.38	9.62	8.14	7.24
Other C	5.31	20.58	15.66	8.52	4.66	2.33	0.93	0.47
Beech	1.66	10.08	13.24	11.37	8.72	6.41	4.62	2.31
Oak	0.93	6.94	11.68	10.77	8.49	6.59	5.22	2.61
B l r.	1.21	7.98	11.75	10.45	8.13	6.15	4.66	2.33
B s r.	1.81	11.95	17.60	15.66	12.18	9.21	6.99	3.49

Table A 4 Annex 8: Distribution of thinning values (m³ o.b./ha yr) used within the model for tree species per age class.

	I	II	III	IV	V	VI	VII	VIII
Spruce	0.45	1.63	1.91	1.69	1.42	1.06	0.75	0.51
Fir	0.68	2.69	3.18	3.09	2.59	1.96	1.40	1.08
Pine	0.68	2.65	2.94	2.06	1.31	0.81	0.48	0.34
Larch	0.53	1.82	1.84	1.59	1.34	1.13	0.96	0.85
Other C	0.08	0.29	0.22	0.12	0.07	0.03	0.01	0.01
Beech	0.21	1.28	1.68	1.44	1.11	0.81	0.59	0.29
Oak	0.12	0.90	1.51	1.40	1.10	0.85	0.68	0.34
B l r.	0.16	1.04	1.53	1.36	1.06	0.80	0.61	0.30
B s r.	0.41	2.71	3.99	3.55	2.76	2.09	1.58	0.79

Annex 5

ACBM Modul
PROD

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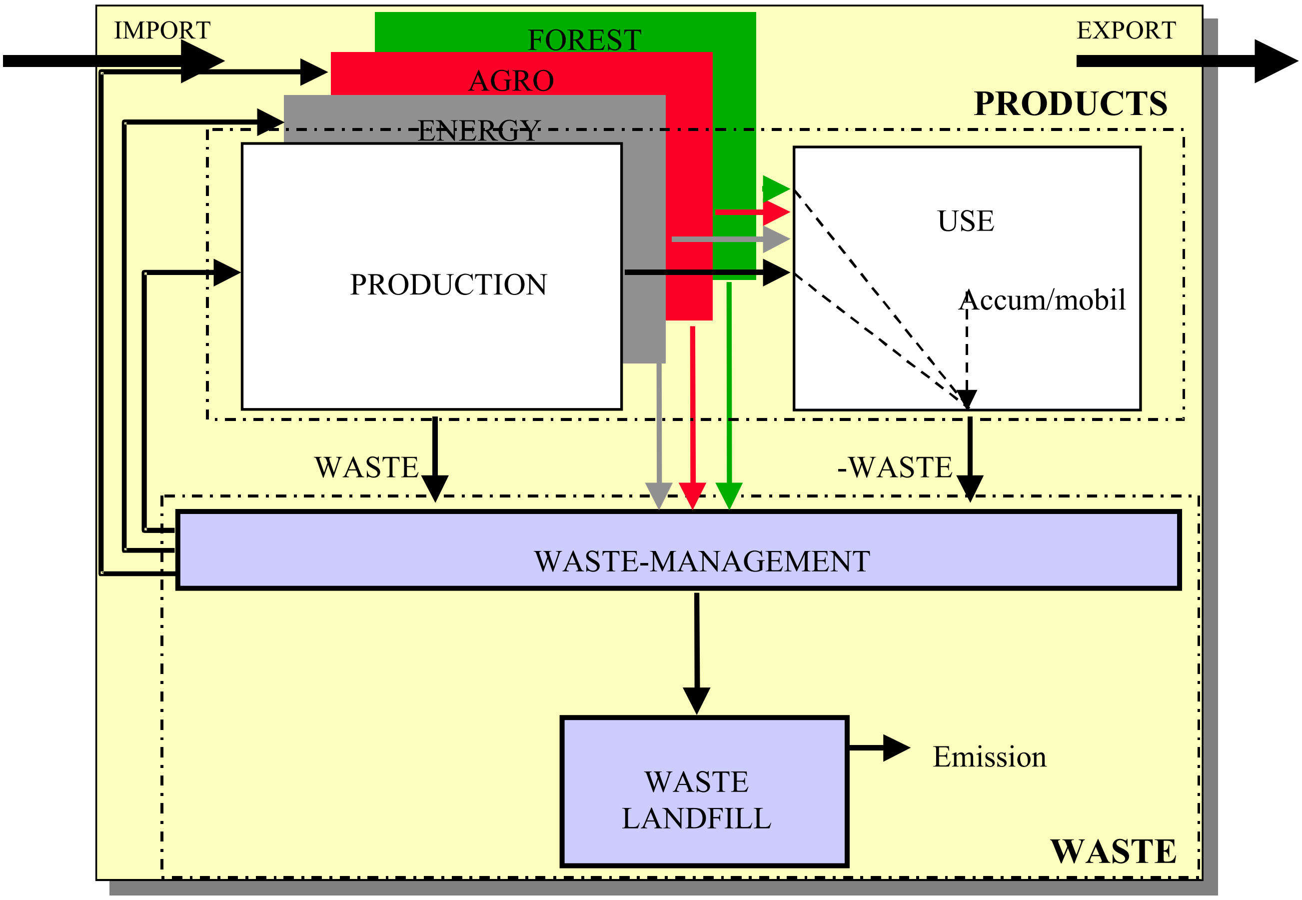
A 5-1 Introduction

According to the general scheme of the project the {PROD} module has on one hand connections to the different “national” modules Agriculture, Forestry, Waste and Energy, on the other hand to the external modules that include import-export, atmospheric emissions and lithosphere (Figure A 5-1).

Figure A 5-1: General structure of the project



The module {PROD} includes consumption, trade and all production sectors that are relevant from carbon content in the products or from energy consumption. The module was structured in the sub-modules (subsystems)

production – P_industry
trade and manufacturing – P_products
other activitie beneath the regarded process – P_other industry
consumption – P_consumption

Each module was divided in subsystems and further in “processes” which are processes of transformation, “pools” for accumulation or mobilization like the consumption, or “dispatchers” for mixing or distributing flows. Horizontally the module was composed of layers describing the most relevant sectors notably food and feed, wood and paper, plastics and chemistry, textiles and leather, minerals and metal industry. All consumed products were assumed to be passed via the production or trade to consumption; therefore there was no direct flow from outside to consumption. Energy supply (for transformation processes and transportation) was provided by the {ENERGY} module with its specified energy mix. Also the emissions of combustion processes were counted in {ENERGY}, only the process emissions were attributed to {PROD}. The iron production was a special case in that respect, as all the energy and coke consumption was covered by {ENERGY}, for consistency reason only the release of carbon in the steel process was counted by {PROD}. As the {PROD} module is a typical “through” module, managing and balancing the inputs, coming from inland raw materials and from those abroad with the outputs to waste was a special challenge. Hereby the internal consumption pool played one major role.

A 5-2 Methodology

A 5-2.1 Data availability

The first step was the creation of a database comprising the material flows and furthermore the carbon flows in the production sector for one or more years. Hereby the lacks in the data sources could be identified and filled as best as possible to describe the development in the production sector in Austria.

In the European Union the production values are recorded following the international Prodcom nomenclature. The system of Austrian Economic statistics was changed to this new structure when Austria joined the European Union 1995 and unfortunately PRODCOM data (NACE-classes) are available at ÖSTAT only since 1995.

Different types of data sources, which are rarely compatible, moreover complicated data acquisition in the production sector. Raw material statistics, production statistics, foreign trade statistics, information from companies, supplemented with additional technological information were used. Amounts sometimes differed depending on the different statistics; in the wood sector for example some statistics did not include small wood in the wood statistics. Inhomogeneities could also be found within the same statistics. To illustrate this: wood is sometimes given in tons and sometimes in m^3 in the foreign trade statistics, with conversion factors that differ with different years and sources. This required a good comparison of data sources, at the appropriate level of aggregation. Data sources used to calculate the balances of the {PROD} module are given in Table A 5-1.

Table A 5-1: Data used for {PROD} module.

Data use	Data source	Data characteristics
Import & Export	Der Außenhandel Österreichs, ÖSTAT	Very disaggregated; due to the variations in dry mass contents, disaggregated data must be used in many cases; there is no separation between intermediates and final products
Products	Industrie- und Gewerbestatistik, ÖSTAT	Higher aggregated in the former system than in NACE, but most values given in physical units, problem with double counting of intermediates, because of internal flows
Raw materials	Industrie- und Gewerbestatistik, ÖSTAT	Same aggregation level as production data, same problems with double counting; mainly data for industry, low quality for “Gewerbe”
Energy	Industrie- und Gewerbestatistik, ÖSTAT	Data available for the whole "Fachverband"; difficult to show consequences of technical measures
Specific sectors	Yearly publications of sector- specific surveys	Medium-aggregated data, sometimes very specific and most useful; for main product groups only, only punctual

Production statistics

As the NACE classification is rather new for Austria and industry is still organized in branches ("Fachverbände") many information sources are still structured along this former scheme. So this approach looked first at the years 1990 up to 1994, in the next steps we actualized the data for the years up to 1997 with the corresponding PRODCOM data. For a consistency check the year 1995 was taken, for which data in old and new structure was available. Then the production development up to 1997 was taken from the PRODCOM data, with consideration of information of the industrial branches. The assignment of the products in PRODCOM nomenclature to the corresponding "Fachverband" was not a problem in most cases. Generally the statistics of the industrial production in Austria is of very good quality, however some production data was not available in mass units (fortunately this was very seldom the case in chemical industry). Those products listed in „Industrie- und Gewerbestatistik“ had to be converted; the conversion was carried out by the multiplication of the production values with coefficients derived from artificial prices taken from the export part of foreign trade statistics. In case of the availability of other physical data (e.g. m³) mass units were derived by the use of physical coefficients (e.g. density). Units like pieces or meters posed problems, here we had to use estimations and expert information.

Raw-Material Statistics

In Austria data on raw material consumption and ancillaries, as well as energy and water consumption are available in the former system of statistical survey from an annual collection.

With the adoption of the NACE system raw material statistics was stopped. There are some discussions on a future annual survey of raw material consumption in Austria, which of course will provide best information. In the meantime we had to rely on information from companies and representatives from industry, in many cases a lot of data remained to be filled up with technological background information. In analogy to the products also a lot of raw materials needed to be converted into mass units, where artificial prices from the import part of foreign trade statistics were used. For some economic activities Input/Output coefficients, worked out by our Institute for 1991, could be used. Although we were happy about the existence of raw material data at least for the years before 1995, the quality of the data was not comparable with that of the other statistical sources, as firms are generally not requested to keep a physical accounting.

Environmental Statistics

Environmental statistics (atmospheric emissions, waste-water, waste) was incorporated into the balances either by the emission flows directly or by means of emission coefficients and the respective flows. Whereas CORINAIR provides a good picture on air emissions such periodical surveys were not available for wastewater.

Since 1998 NAMEA projects were started in Austria. They aimed at establishing a general framework for documenting data on air, water emissions and waste for all sectors of the public economy in NACE nomenclature. They used no separated surveys, but a conversion of existing data to NACE-classes at two-digit level. Unfortunately they are presently published only for 1994, but its continuity and the common framework promises increasing data quality and consistency for the future.

A 5-2.2 Data and knowledge gaps

The most demanding step of the carbon balance was the establishment of a valid product material balance. It showed clearly the demand for consistent industrial physical statistics based on better-qualified physical accounting at firm level. This means that first a system of physical accounting for the firms might be needed and , secondly, a homogenous national system of physical input/output statistics should guide the first one. Lacking this consistent data at the moment a stepwise procedure was applied to set up a material flow balance.

The first step was to carry out a regular IN-OUT balance of industrial sectors, based on national statistics.

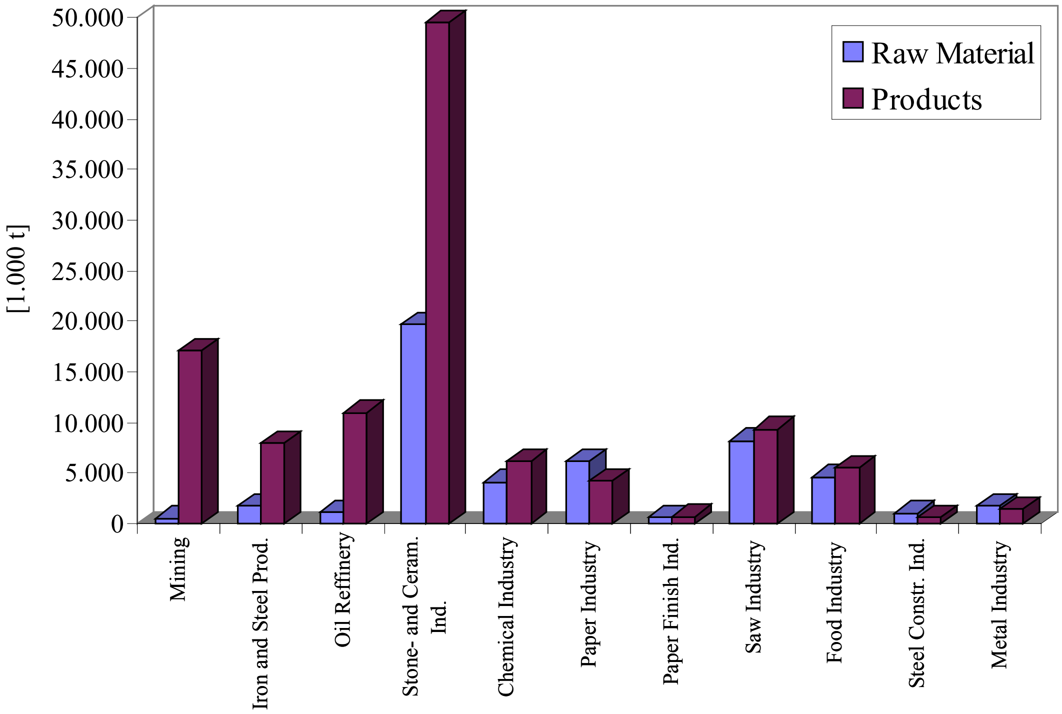
The second step was to adjust the balance by comparing input and output flows by finding technological connections and intermediate processes, and by adding internal (hidden) flows, loops and inputs not included in statistical data. This work required frequently investigation at a very detailed level.

The last step was the combination of the material balances of the sub-processes through construction of material flow chains to a balance of the whole branch or sector. The knowledge of the sector internal flows was essential to avoid incorrect multiple counting and to calculate the correct and corresponding data of materials flows entering and leaving a sector, which is finally the essential information for determining material demand or output.

Rough IN-OUT Balances out of statistical data

By comparing the input and output flows of the single sectors there usually remain remarkable Figure A 5-2). Reasons for that are on one hand flows (mainly inputs) that are not counted in the statistics because of no monetary value (“hidden flows”) or not published due to secrecy reasons and on the other hand multiple counting of products (sector internal use), leading to an overestimation of the outputs.

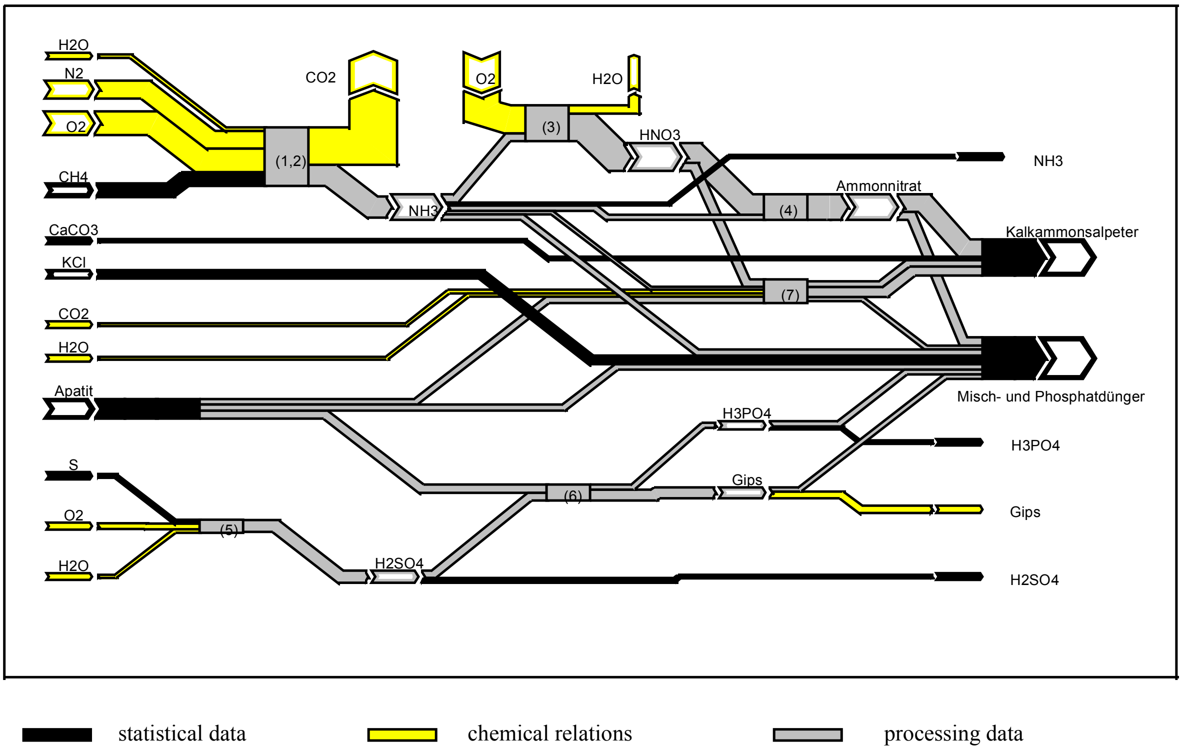
Figure A 5-2: Comparison of the input and output material flows from national statistics



Creating a Complete Balance

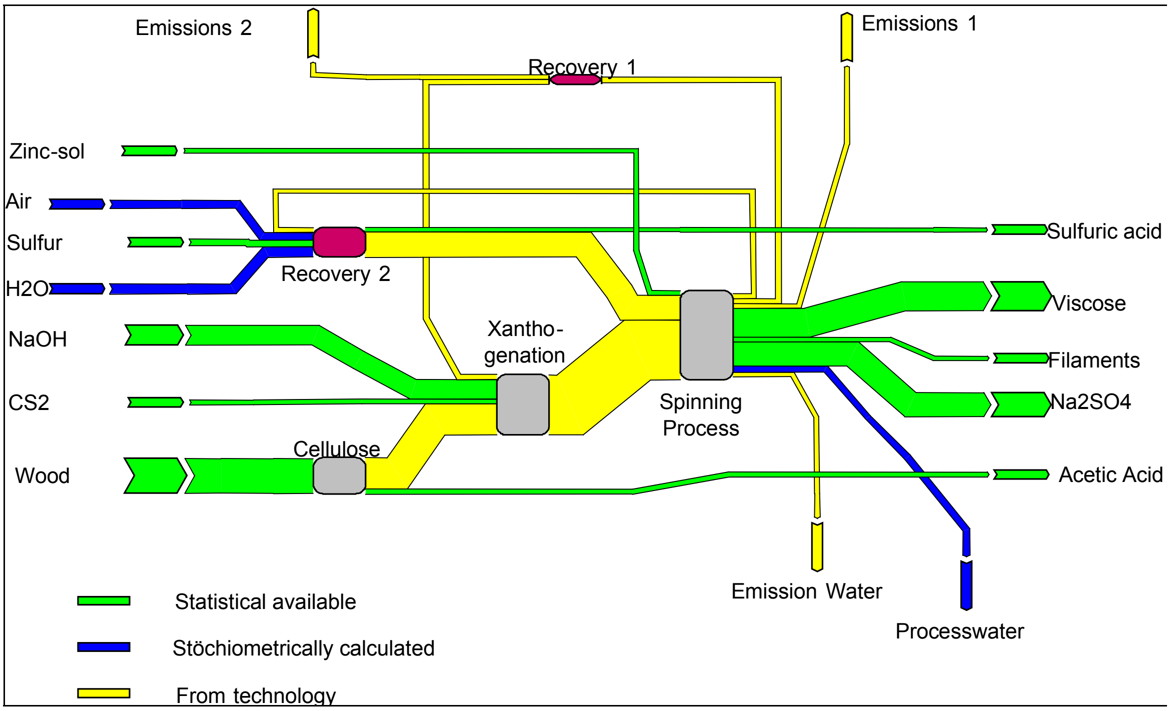
In many cases the information out of statistical data was not enough to create a complete balance. To fit the balance we gave our consideration to the raw materials and the products and tried to find processes to link them. For such a balance with technologic background, obviously, knowledge about the structure of industry and the used processes in the respective country is generally necessary. During the project it was important to specify an appropriate aggregation level for the several branches, an important prerequisite to achieve the desired results. With the help of technologic and chemical process know-how we tried to supplement the balance with not documented flows as shown in Figure A 5 – 3 and arrived finally at a fitting balance.

Figure A 5-3: Example for a complete balance for the fertilizer industry in Austria



Hereby recovery and recycling processes played an important role. With a rough idea about the general structure and by looking at a rather detailed process-level it was possible to reduce the number of unknown variables sufficiently to close the balance (Figure A 5-4).

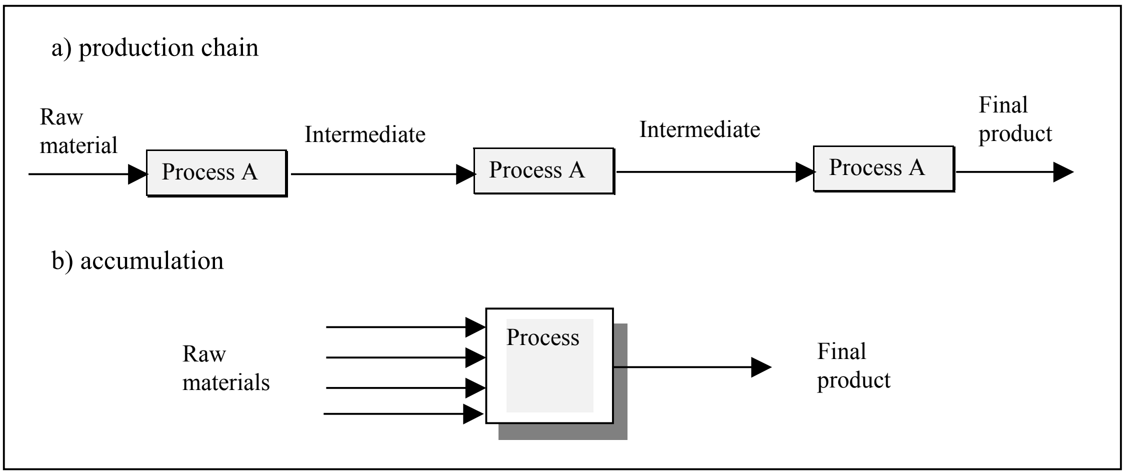
Figure A 5-4: Creating a balance of a branch in chemical industry with recovery processes



Construction of Material Flow Chains

In order to count the raw material consumption of a sector, it is very important to follow the way of the products. In case of products which are further processed in process chains like in plastic industry, the raw materials should be counted only once at the entrance to the chain. Consequently also the products should be counted only at the boundary to consumption for estimating material intensity. On the other hand a lot of industrial processes accumulate all inputs in the product, which is then sold to the market. Therefore all inputs have to be counted for material intensity (Figure A 5-5). Such information on the type of the process was not visible from statistical data and had to be added from technology point of view.

Figure A 5-5: Types of production processes



In any case, the more disaggregated the analysis was done, the more attention had to be put on this step. Disaggregated investigation facilitated on the one hand creating and fitting the balance, but needed more efforts in calculating the correct values of sector in- and outputs.

A 5-2.3 Model design

The module was composed of different layers describing the relevant sectors. Each sector was analyzed at an appropriate level of aggregation to identify cause-effect chains and to avoid the possible double counting of materials in process chains (as described above). However considering the complexity of the production-system in Austria, a certain level of aggregation had to be maintained. For the work the hereunder-listed aggregates were chosen:

Wood and paper:

- Logs
- Pulp and paper
- Boards
- Wood products
- Planks and residues

Food and feed

- Cereals and feed
- Sugar and products
- Fruits and vegetables
- Meat and animals
- Fats and oils
- Milk and products

Textile and leather

Chemistry

- Fertilizers
- Resins
- Bitumen
- Lubricants
- Paints and solvents
- Plastic
- Rubber
- Other chemicals
- Cleanings and cosmetics

Process industry

- Minerals
- Metals

As the data of the selected aggregates should be able to be combined to any higher aggregation level a common structure was needed. This structure should on one hand allow the merge of production data with import-export of raw materials, intermediates and final products. On the other hand a link with waste data, necessary for prospective scenarios, should be facilitated by the structure. The finally selected structure (Figure A 5-6) distinguishes between

- Sources, inland or import
- Production processes
- Further manufacturing and trade of the products
- Destination in consumption with possible accumulation or mobilization
- Other production processes

The collected data was compiled to the respective flows according to the general structure. Table A 5-2 shows the structure of the data sheets exemplarily for 1990. To get a better imagination on the magnitude of the flows the values of the flows were transformed to a flow-chart for the whole module, which is shown in Figure A 5-7.

Figure A 5-6: General structure of the {PROD} module

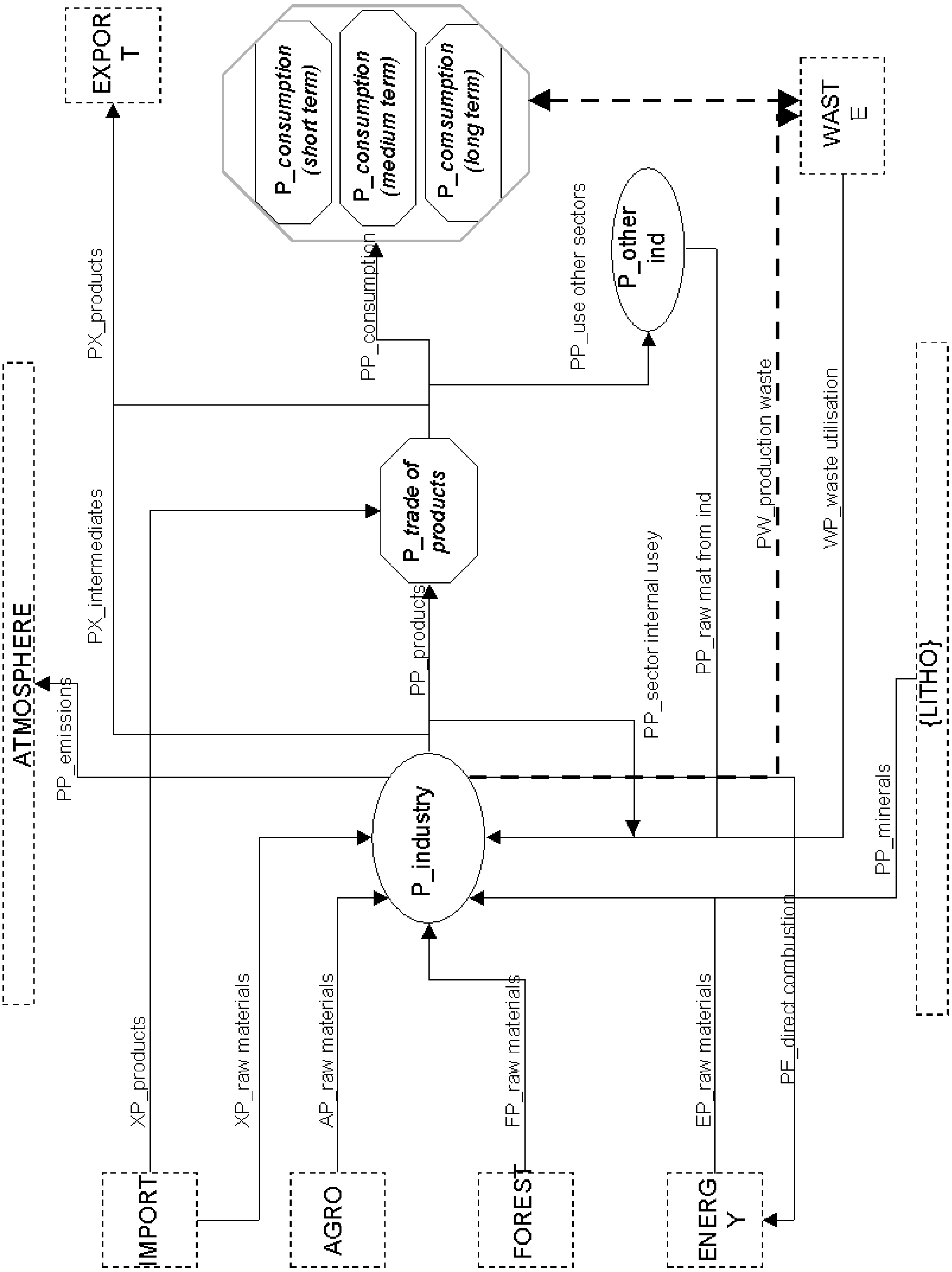
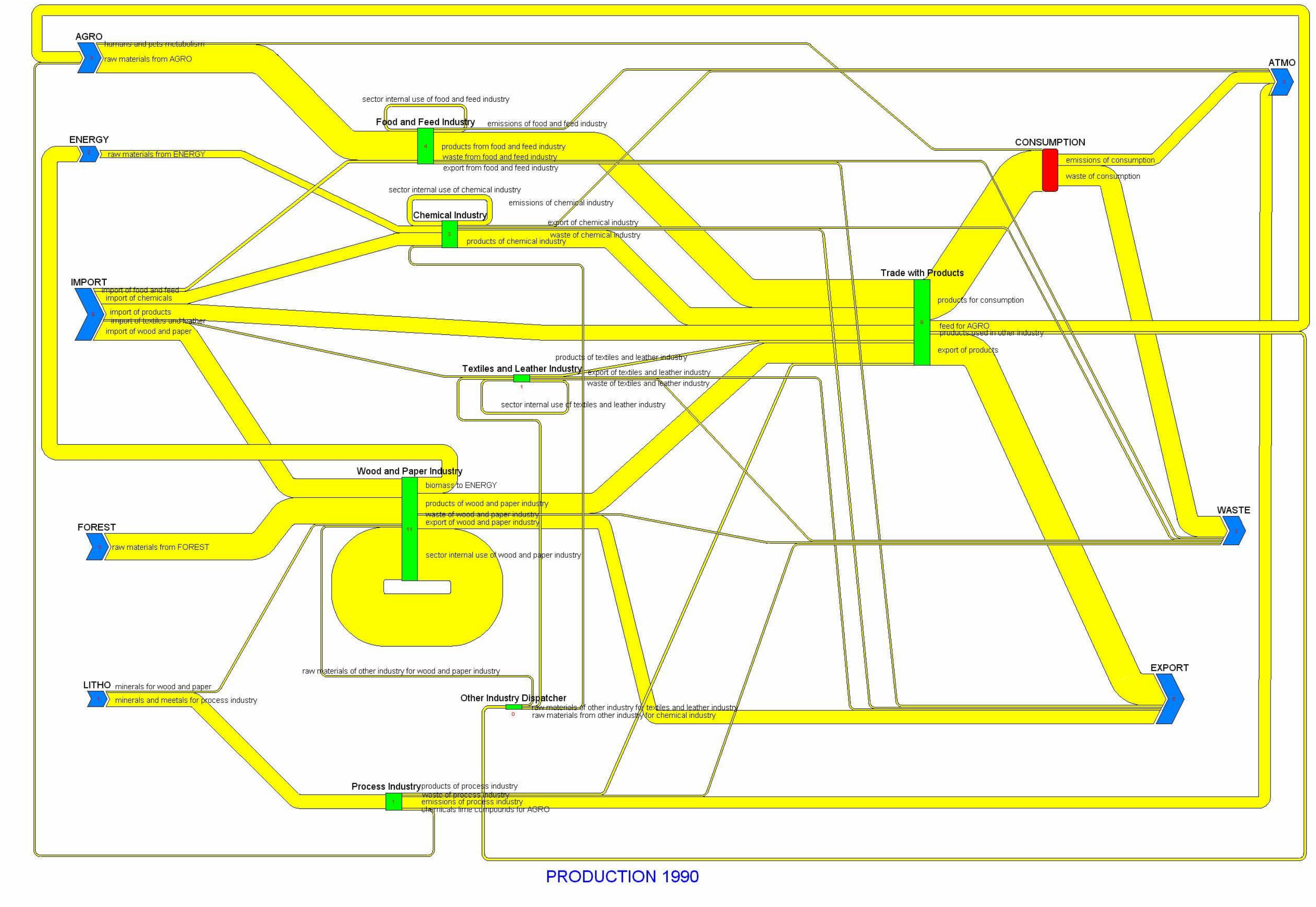


Table A 5-2: Structure of the data sheets exemplarily for 1990

	1990		1990		1990		1990		1990	
	food and feed		**chemistry**		**wood and paper**		**textiles and leather**		**process industry**	
	Mat.flow in t	C-flow in Mio t	Mat.flow in t	C-flow in Mio t	Mat.flow in kt	C-flow in Mio t	Mat.flow in t	C-flow in Mio t	Mat.flow in t	C-flow in Mio t
XP_raw materials	1.810.610	0,300	1.663.723	1,278	7.066	2,039	208.786	0,091		
AP_raw materials	12.414.907	2,896								
FP_raw materials					10.366	2,738				
EP_raw materials			984.704	0,725						
PP_raw mat oth ind			24.076	0,016			658.697	0,258		
PP_sector internal use	1.674.070	0,202	686.005	0,515	16.634	5,454	363.766	0,146		
WP_waste utilisation	6.343	0,002	45.752	0,039	967	0,291	34.374	0,014	-	0,022
LP_minerals					724	0,023			-	1,475
SUM Input Production	15.905.930	3,400	3.404.259	2,572	35.851	10,614	1.265.624	0,508	-	1,497
PP_products	9.853.811	2,978	2.539.656	1,798	6.684	2,102	595.667	0,232	-	0,222
PX_intermediates	189.378	0,040	106.077	0,127	4.208	1,404	289.297	0,123		
PE_direct combustion					6.075	1,581				
PW_production waste	876.176	0,133	104.646	0,080	260	0,074	16.893	0,007	-	0,041
PP_to sector internal use	1.674.070	0,202	686.005	0,515	18.640	5,454				
PT_emissions	3.312.495	0,048	77.951	0,058			363.766	0,146	-	1,211
PA_chemicalslime compounds									-	0,022
SUM Output Production	15.905.930	3,401	3.514.336	2,578	35.868	10,615	1.265.624	0,508	-	1,497
XP_products	281.073	0,109	899.368	0,719	1.231	0,400	136.647	0,080		
AP_human and pets metabolism	156.640	0,033			7.916	2,502				
SUM Products	10.291.524	3,121	3.820.292	2,841	4.099	1,283	732.314	0,312	-	0,222
PX_products	975.021	0,331	1.894.766	1,489	149	0,053	70.656	0,042		
PP_use in other industry	64.346	0,026	353.562	0,193						
PA_feed for animal	3.298.646	1,277								
PP_consumption	5.953.511	1,488	1.495.464	1,120	3.668	1,165	661.658	0,270	-	0,222
PW_waste from users	5.953.511	0,119	803.592	0,636	3.036	0,967	111.691	0,045	-	0,020
PT_emissions of consumption	3.813.333	1,040	167.690	0,143						

Figure A 5-7: Flow-chart for the whole module



A 5-2.4 Scenarios

Whereas data for the time period from 1990 to 1997 (and 1998 in some cases) was available, the development from 1999 until 2010 had to be estimated with the model. As most determining for the behavior of the {PROD}-module the development of the production and of the consumption flows were selected. The behavior of the flows was lead by Driving Parameters (DP), which were formulated as the annual, relative increase based on the previous year: positive values lead to an increase, negative values to the contrary. As it was the relative annual increase, constant rate resulted in a curve with a progressive slope. Linear trend required a diminishing yearly increase rate.

To be consistent in all the modules the conditions for future development were specified in two different scenarios.

Scenario 1: No major changes

The characteristic of Scenario 1 was the estimated business as usual philosophy, a continuation of the trends up to 1998. Therefore, the trend of the years 1990 to 1998 was continued for the single flows. The DPs were adjusted to obtain continuous and realistic development of the flows. Variations were hereby smoothed so that the results represent only the average development. In those branches with comparably high increase rates a diminishing behavior, approaching to a maximum was insinuated to remain in a realistic range.

The used DPs are listed in Table A 5-3, distinguished between production and consumption parameters. They describe the development in a business as usual, which was the basis for the changes in scenario 2 towards a more sustainable economy.

Difficulties

The continuation of the trends in a rather smooth form represents of course only an average and cannot be seen as the real situation in single years for the single product groups, which is significantly influenced by economic and social conditions. But it should be sufficient as a vision of the general trend, which was essential for that project.

The assumed maxima in strongly increasing branches might be of significant effect on the final situation in 2010. As we couldn’t find an objective basis they were mainly estimated to what seemed reasonable.

Scenario 2: Towards sustainability

In contrary to Scenario 1 in Scenario 2 a more sustainable situation in economy and consumption should be described. However, feasibility and plausibility of the assumptions should be obeyed. The changes of the DPs compared with Scenario 1 were made according to the principles of sustainability, laid down in driving bags and driving forces. The driving force *lifestyle* had the greatest influence on consumption, whereas *economic development* determined the production development.

Consequently those branches using high amounts of fossil raw materials (bitumen, lubricants) were assumed to get decreasing behavior or only slight increase (other chemicals, plastics, rubber). On the other hand the use of renewable raw materials (wood and wooden products) was forced and a trend to more vegetarian products and less meat was implemented.

Difficulties

It was attempted to choose plausible, reasonable and realistic assumptions, although direct economic requirements could only rarely be considered.

Table A 5-3: DPs for Module {PROD}

Driving Force: CONSUMPTION DEVELOPMENT because of lifestyle

No Major Changes	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
DPP_Consumption bitumen lubricants	1,08	1,07	1,05	1,04	1,03	1,02	1,01	1,00	0,99	0,98	0,97
DPP_Consumption sugar	2,15	2,05	1,96	1,88	1,80	1,72	1,65	1,58	1,51	1,45	1,39
DPP_Consumption cereals, feed	1,82	1,79	1,76	1,73	1,70	1,67	1,64	1,61	1,59	1,56	1,54
DPP_Consumption fats, oils	-0,25	-0,25	-0,25	-0,25	-0,25	-0,25	-0,25	-0,26	-0,26	-0,26	-0,26
DPP_Consumption fruits, vegetables	-0,42	-0,42	-0,43	-0,43	-0,43	-0,43	-0,43	-0,44	-0,44	-0,44	-0,44
DPP_Consumption logs	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08
DPP_Consumption meat	-0,87	-0,88	-0,89	-0,90	-0,90	-0,91	-0,92	-0,93	-0,94	-0,95	-0,96
DPP_Consumption_milk	1,08	1,07	1,06	1,05	1,04	1,03	1,02	1,01	1,00	0,99	0,98
DPP_Consumption other chemicals	1,37	1,36	1,34	1,32	1,30	1,29	1,27	1,25	1,24	1,22	1,21
DPP_Consumption plastics, rubber	2,87	2,72	2,58	2,45	2,34	2,23	2,14	2,05	1,97	1,89	1,83
DPP_Consumption pulp and paper	1,54	1,51	1,49	1,47	1,45	1,43	1,41	1,39	1,37	1,35	1,33
DPP_Consumption textiles and leather	-0,41	-0,41	-0,41	-0,41	-0,41	-0,42	-0,42	-0,42	-0,42	-0,42	-0,42
DPP_Consumption wood products	1,90	1,86	1,83	1,80	1,77	1,74	1,71	1,68	1,65	1,62	1,60

Toward Sustainability	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
DPP_Consumption bitumen lubricants	-1,00	-1,00	-1,00	-1,00	-1,00	-1,00	-1,00	-1,00	-1,00	-1,00	-1,00
DPP_Consumption sugar	2,21	2,21	2,13	2,07	2,00	1,94	1,88	1,83	1,78	1,72	1,68
DPP_Consumption cereals, feed	2,65	2,62	2,59	2,56	2,53	2,50	2,75	3,00	3,25	3,50	3,75
DPP_Consumption fats, oils	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25
DPP_Consumption fruits, vegetables	3,00	3,00	3,25	3,50	3,75	4,00	4,25	4,50	4,75	5,00	5,25
DPP_Consumption logs	1,50	1,50	1,55	1,60	1,65	1,70	1,75	1,80	1,85	1,90	1,95
DPP_Consumption meat	-1,00	-1,00	-1,15	-1,30	-1,45	-1,60	-1,75	-1,90	-2,05	-2,20	-2,35
DPP_Consumption_milk	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
DPP_Consumption other chemicals	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
DPP_Consumption plastics, rubber	2,87	2,30	1,84	1,47	1,18	0,94	0,75	0,60	0,48	0,39	0,31
DPP_Consumption pulp and paper	2,00	2,00	2,15	2,30	2,45	2,60	2,75	2,90	3,05	3,20	3,35
DPP_Consumption textiles and leather	-0,40	-0,40	-0,38	-0,35	-0,33	-0,30	-0,28	-0,25	-0,23	-0,20	-0,18
DPP_Consumption wood products	1,80	1,80	1,85	1,90	1,95	2,00	2,05	2,10	2,15	2,20	2,25

Driving Force: PRODUCTION DEVELOPMENT because of economic development

No Major Changes	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
DPP_Production wood products	2,34	2,29	2,24	2,19	2,14	2,10	2,06	2,01	1,97	1,94	1,90
DPP_Production bitumen, lubricants	2,80	2,72	2,65	2,58	2,52	2,45	2,39	2,34	2,29	2,23	2,19
DPP_Production cereals_and_feed	0,28	0,28	0,28	0,28	0,28	0,28	0,28	0,28	0,28	0,27	0,27
DPP_Production fats_oils	-0,03	-0,03	-0,03	-0,03	-0,03	-0,03	-0,03	-0,03	-0,03	-0,03	-0,03
DPP_Production fruits, vegetables	-0,20	-0,20	-0,20	-0,20	-0,20	-0,20	-0,20	-0,20	-0,20	-0,20	-0,20
DPP_Production logs	1,88	1,85	1,81	1,78	1,75	1,72	1,69	1,66	1,64	1,61	1,58
DPP_production meat	1,36	1,34	1,32	1,30	1,29	1,27	1,25	1,24	1,22	1,21	1,19
DPP_production milk	1,08	1,07	1,06	1,05	1,04	1,03	1,02	1,01	1,00	0,99	0,98
DPP_Production other chemicals	0,91	0,91	0,90	0,89	0,88	0,87	0,87	0,86	0,85	0,84	0,84
DPP_Production plastics, rubber	2,92	2,76	2,62	2,49	2,37	2,26	2,16	2,07	1,99	1,92	1,84
DPP_Production process industry	2,83	2,75	2,68	2,61	2,54	2,48	2,42	2,36	2,31	2,26	2,21
DPP_Production pulp and paper	1,65	1,62	1,60	1,57	1,55	1,53	1,50	1,48	1,46	1,44	1,42
DPP_Production resins	-0,52	-0,52	-0,52	-0,53	-0,53	-0,53	-0,53	-0,54	-0,54	-0,54	-0,55
DPP_Production textiles and leather	-3,19	-3,30	-3,41	-3,53	-3,66	-3,80	-3,95	-4,11	-4,29	-4,48	-4,69

Toward Sustainability	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
DPP_Production wood products	2,25	2,25	2,28	2,30	2,33	2,35	2,38	2,40	2,43	2,45	2,48
DPP_Production bitumen, lubricants	-1,86	-1,86	-1,89	-1,92	-1,95	-1,98	-2,01	-2,05	-2,08	-2,12	-2,16
DPP_Production cereals_and_feed	0,50	0,50	0,75	1,00	1,25	1,50	1,75	2,00	2,25	2,50	2,75
DPP_Production fats_oils	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
DPP_Production fruits, vegetables	3,00	3,00	3,25	3,50	3,75	4,00	4,10	4,20	4,30	4,40	4,50
DPP_Production logs	1,00	1,00	1,05	1,10	1,15	1,20	1,25	1,30	1,35	1,40	1,45
DPP_production meat	0,34	0,34	0,32	0,30	0,29	0,27	0,25	0,24	0,22	0,21	0,19
DPP_production milk	0,00	0,00	0,10	0,20	0,30	0,40	0,50	0,60	0,70	0,80	0,90
DPP_Production other chemicals	0,42	0,42	0,41	0,40	0,39	0,39	0,38	0,37	0,36	0,36	0,35
DPP_Production plastics, rubber	2,16	2,16	1,86	1,59	1,34	1,12	0,91	0,73	0,56	0,40	0,25
DPP_Production process industry	2,25	2,25	2,18	2,11	2,04	1,98	1,92	1,86	1,81	1,76	1,71
DPP_Production pulp and paper	1,67	1,67	1,65	1,64	1,63	1,61	1,60	1,59	1,58	1,57	1,56
DPP_Production resins	-0,02	-0,02	-0,02	-0,03	-0,03	-0,03	-0,03	-0,04	-0,04	-0,04	-0,05
DPP_Production textiles and leather	-2,80	-2,80	-2,91	-3,03	-3,16	-3,30	-3,45	-3,61	-3,79	-3,98	-4,19

Table A 5-4: Driving bags and driving forces used in the {PROD} module

	NO MAJOR CHANGES (2000-2010)	**TOWARDS SUSTAINABILITY (2000-2010)**
DB ECONOMIC DEVELOPMENT	**Economic development will be around growth rates of 2,5 % GNP p.a. Contribution of agriculture to GNP will slightly decrease. Growth rates will mainly come from services and leisure tourism. Production will shift from primary to secondary products.**	**Economic development will be around growth rates of 2% GNP p.a. Contribution of agriculture to GNP will remain the same. Growth rates will mainly come from services and leisure tourism. Production will shift from primary to secondary products, with more products from renewable raw materials.**
DF Production	Continuation of current trends depending on the respective products.	Slight decrease in trend for fossils, increase in production of wood products.
DB LIFESTYLE	**Continuation of 1990-2000 rates of single households, environmental awareness, nutrition patterns, vehicle mileages. Increasing vehicle use for „fun“ matches decreasing commuting because of teleworking.**	**Continuation of 1990-2000 trends, but less vehicle use (decrease in annual vehicle mileage by 5 % until 2010), more environmental awareness, more vegetarians. Increase of natural forests and changes of forest management strategies**
DF Consumption	Continuation of current trends depending on the respective products.	Decrease in trend for fossils, increase in consumption of wood products.

A 5-2.5 Model Formulation

The calculation of the single flows in the different aggregates of the sectors was done individually for each case and took into consideration the actual connections e.g. whether a raw material was provided from one of the other modules, or came from the external modules {IMPORT} or {LITHO}.

The leading parameters for the calculation of the flows were the development of consumption and that of production. For the period from 1990 to 1998, the model showed the values of the produced database. For 1999 the values were extrapolated, after 1999 the DPs determined the flows of the processes.

In the *production processes* the amount of products to trade was the determining flow. From them the raw material demand for the produced products was calculated. It could be provided by the other modules, from the {IMPORT} or {LITHO} or could come from other processes of the same sector, as in fodder production and wood industry. The production waste, the emissions and the exported intermediates were calculated with proportions or coefficients out of the product flows. Basis for all the proportions was the estimation in the years 1990 – 1998.

The sector *food and feed* was supplied with raw materials mainly from AGRO. The difference to the totally required raw materials was covered by the {IMPORT}. A part of the residues of the food processes could be utilized internally in the feed industry. Some residues like the skins coming from AGRO to the slaughterhouses, were transferred as raw material to another production branch (other industry), the textile and leather process. The publicly collected and recycled raw materials were delivered by {WASTE}. The by-products, the production waste and the exported intermediates were calculated with proportions from the amount of products, the process emissions were assumed to be proportional to the production activity.

In the sector *wood and paper* the required amount of industrial roundwood from {FOREST} to logs was calculated with an annual increase based on 2000. In the “no major changes” scenario the annual increase was estimated with 1%, in the “toward sustainability scenario” with 1,2%. This increases were chosen with agreement of the {FOREST} module and IIASA (Annex 8). The difference to the required amount was calculated from the {IMPORT}. The other processes of the wood sector received their raw materials sector internally. The difference to the required amount was covered by the {IMPORT}, too. Pulp and paper used waste paper from public collection that was delivered by {WASTE}. The amounts of production waste and by-products were calculated from the amount of products. The production waste consisting mainly of wood residues was passed over to {ENERGY}.

In the sector *chemistry* the raw materials were obtained from {ENERGY} or {IMPORT}, some recycled products of the chemistry sector were delivered directly by {WASTE}. Up from 1998 the relation in raw material provision among {ENERGY} and {IMPORT} was calculated out of the trend from 1990 to 1997 and assumed as constant for the years after 2000. The amounts of exported intermediates were calculated from the trends of 1990 to 1997. The production waste was assumed as proportional to the production output, derived from the situation from 1990 – 1998.

In the sector *textiles and leather* raw materials were provided by other sectors, by sector internal flows and as recycled material from {WASTE}. The proportion of the sector internal use of the output was determined out of the period 1990 to 1997 and kept constant since then. The same procedure was applied to calculate production waste. The difference to the totally required raw material was assumed as {IMPORT}. The exported intermediates were calculated in proportion to the development in production.

For the sector *process industry* raw materials exceeding the recycling amounts supplied by {WASTE} were required from {LITHO}. The emissions of the carbon in the iron, released during steel process were calculated with stoichiometry. The amount of the lime compounds used by AGRO was demanded by AGRO. The production waste was assumed as proportional to the output due to the situation from 1990 – 1997.

The trade process is a simple balance of the inputs coming from production and import resulting in outputs to export and consumption without any change in carbon-composition. As in most of the cases no data on consumption existed, but export was well documented, consumption was calculated for the years 1990 to 1997 from the difference.

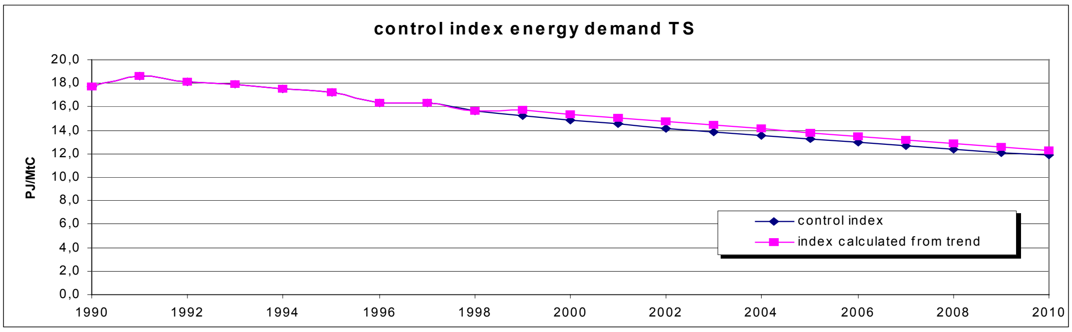
For the scenarios consumption was the second determining process, the DPs for the single products in the sectors defined the consumption behavior up from 2000. It was calculated from the trend of the previous years and extrapolated with respect to the conditions in the two scenarios. In contrary to the years before 1998 the export of products was calculated as the rest of the trade amounts minus the consumption and minus the products further processed in other branches of industry.

The consumption process was created as a pool, as it had no due balance. Any accumulation or mobilization was calculated from the annual difference of inputs and outputs. Since there are no data for the amounts accumulated already in the past in consumption, 1990 was started with an empty pool, being filled or emptied in the following years.

As inputs into the pool all the flows to consumption, controlled by the DPs were taken. Additionally the direct purchase in AGRO and the recycled bitumen were counted. The Output flows comprised besides the consumption waste also breathing, calculated with an average breathing-coefficient per inhabitant, waste water and the emissions of VOC´s. The annual amount of waste was taken from the database up to 1998 and extrapolated for 1999. Up from 2000, the amount of waste was calculated for every product flow to consumption, taking into consideration a share of accumulation, which was obtained from the development of the recent years. Generally it was assumed that the total accumulation in consumption would approach slowly a saturation level for every product group in the regarded time frame. For the VOC´s emission out of chemistry products no accumulation in consumption was postulated due to short lifetime, so that the difference between the VOC-consumption and the VOC-waste was counted as emission. The wastewater flows were extrapolated from the trend of the last years.

As the {ENERGY} module provided the energy supply for transformation processes and transportation with its specified energy mix there was no direct relation between the developments in {ENERGY} and {PROD}. Therefore the specific energy consumption, calculated out of the total energy demand of production and the sum of all carbon flows going through production, was established as a control index. Figure A 5 – 8 shows the development of the control index for the Scenario Towards sustainability.

Figure A 5-8: Control index energy demand

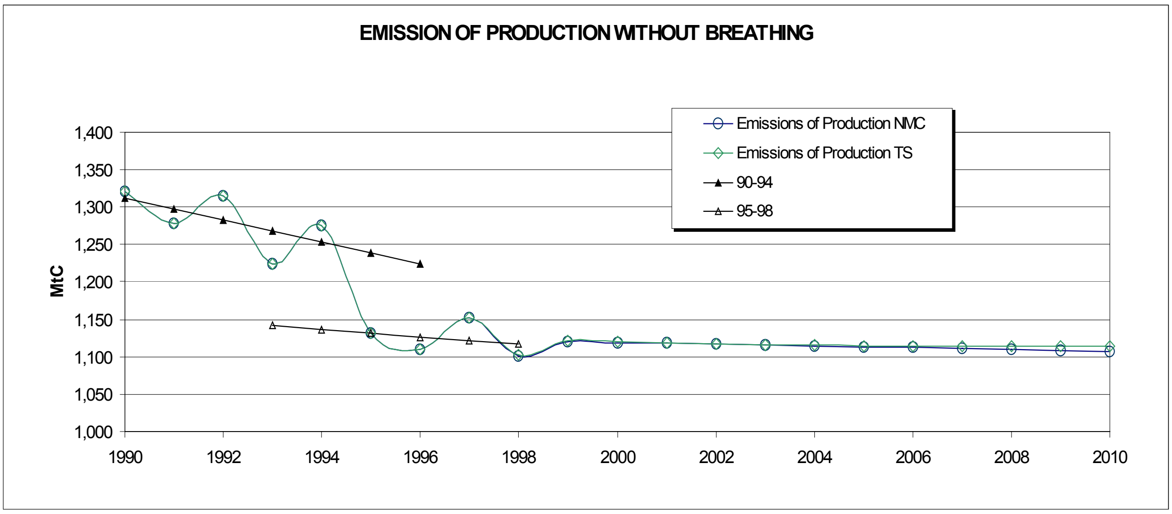


A 5-3 Results

A 5-3.1 Dynamic model behavior

In the following figures the general dynamic behavior of the {PROD} module and the differences between the two scenarios are outlined. The development of the total flows in the scenarios (NMC = no major changes, TS = towards sustainability) is compared for emission, consumption, products, import, export and the waste amounts.

One general problem, which is visible in many figures, was the inconsistency in the system of statistic data collection before and after 1995. So the data are not representing the same sample and are of course not fully comparable. However, we tried to smooth too severe rupture by taking adequate data for both periods, this lead to more or less success in the single sectors.

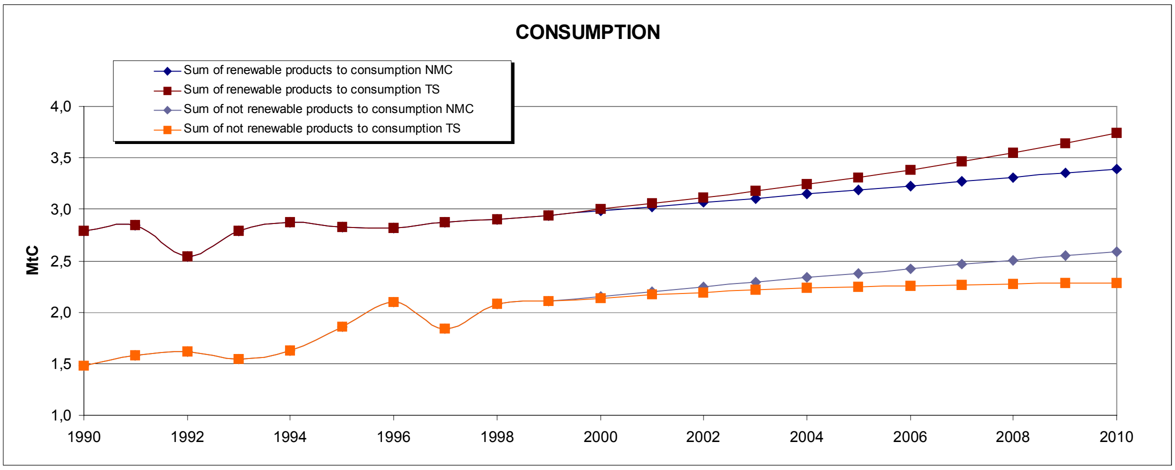


The emissions of production show such a break in the development before and after 1995, which made the expectation of the future development difficult. They result mainly from the processes fertilizer, food, cement, glass and ceramic production, estimated out of the trends, as well as the release of carbon in steel manufacturing, calculated from the production activity. To show the difference in the two data systems the trends were extrapolated to overlap for some years. The values according to the old systematic are definitely higher than those up from 1995.

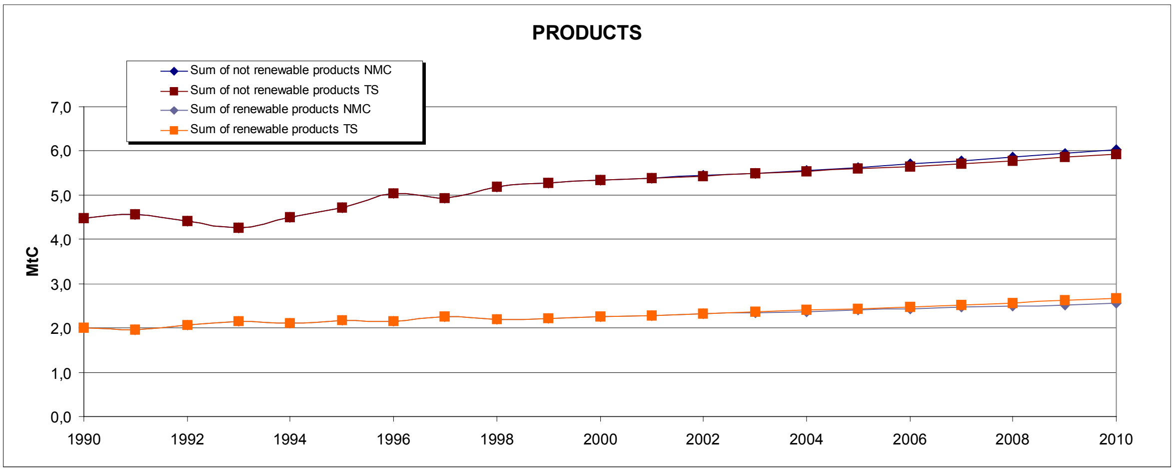
As the lower values and the rather constant development seemed reasonable the latter data according to the new NACE system have been used for the scenarios.

As can be seen no major difference occurs between the scenarios. Nearly one half of the emissions is caused by fertilizer production. Despite a reduction of fertilizer use in agriculture the forced use of wooden products led to enhanced application of resins, produced in linkage with the fertilizer process, and therefore to slightly higher values for the sustainability scenario. It implied also a shift to enhanced use of cereals, leading to more emissions from that processes. On the other hand the steel production and their emissions was decreased which nearly outweighed that increase.

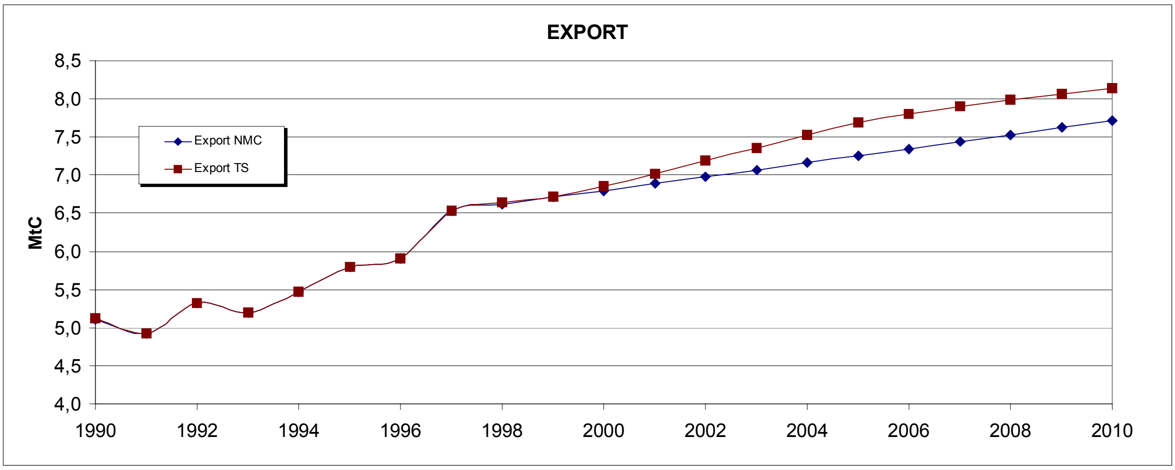
For a comparison with the total module human breathing would need to be added. It is a constant value as the population was assumed to remain constant in that period.



The total annual consumption shows a comparably more consistent behavior also for the period from 1990 to 1998. One of the major cornerstones of the sustainability scenario was the forced use of renewable materials and the reduction of fossils. Accordingly this behavior is visible in the results. Whereas “no major changes” led to an increase for both flows, in the sustainability scenario the increase in the use of fossils could be stopped, due to changes of the development in the consumption of plastics and rubber. The renewable products profited from that, mainly the wood products. The consumption of cereals increased, too, caused by a life style change towards more vegetarians.

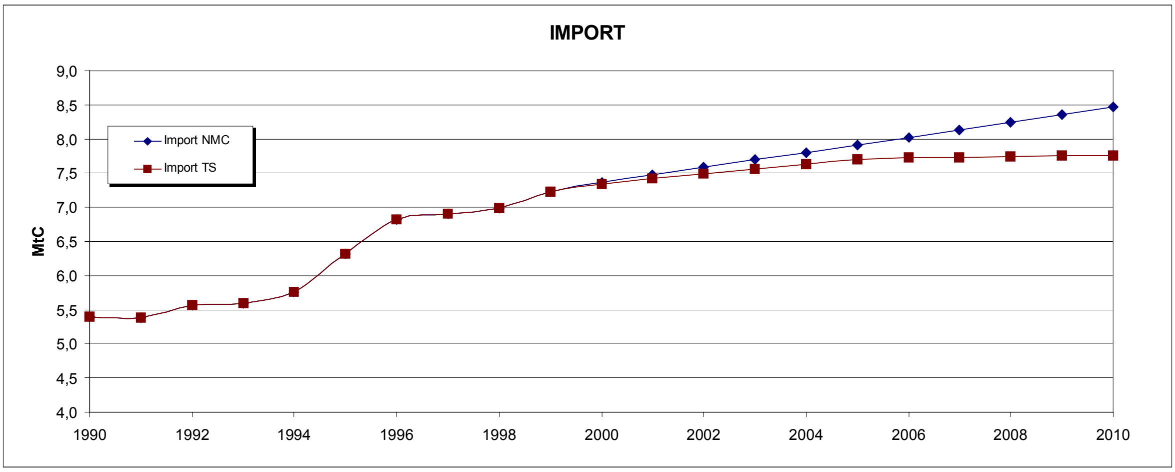


The total annual production for renewable and non-renewable flows shows the same behavior as in consumption.



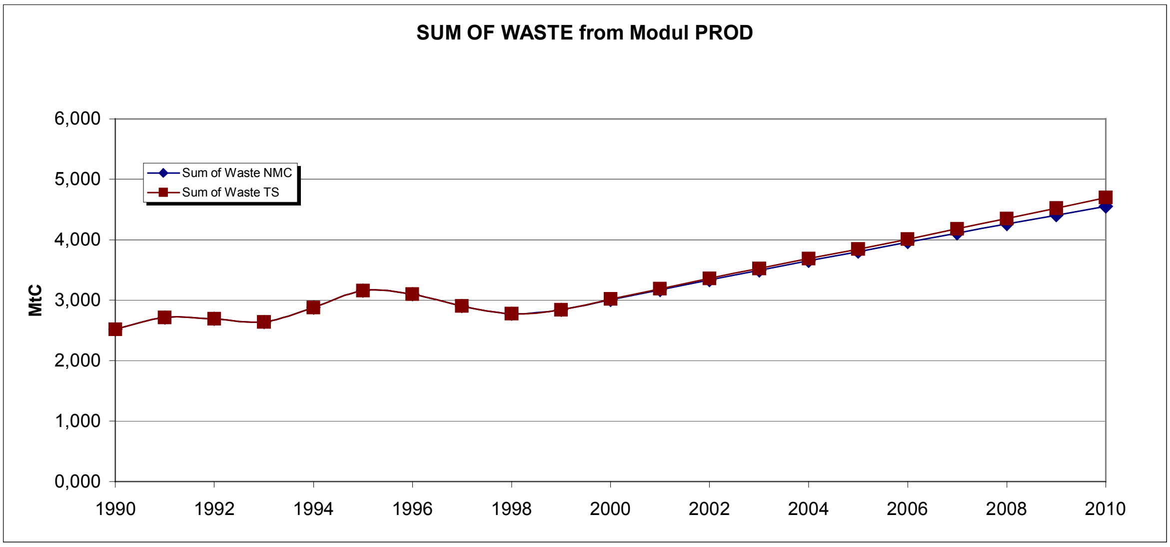
Export shows from 1990 up to 1998 a clear increasing tendency, which is continued especially in the sustainability scenario. This effect comes from the tendency to vegetarians, implying a reduction of husbandry and a lesser demand for feed, resulting in a surplus of cereals that was exported. A similar effect could be observed for the plastic products. The assumption of decreasing consumption at a relative constant production activity contributed to the rise of export remarkably. On the other hand export of wood and wooden products decreased due to enhanced inland consumption.

In contrast the export in the “no major changes” scenario had a slower increase.



At the import of products and raw materials there seem to be two distinct levels in the period from 1990 - 1998, maybe caused again by statistic inconsistency. A lower level before 1994 and a higher one after 1996, both of them with only slight increases. From that development an increasing trend resulted for the “no major changes scenario”, having moreover in mind the tendency towards globalization.

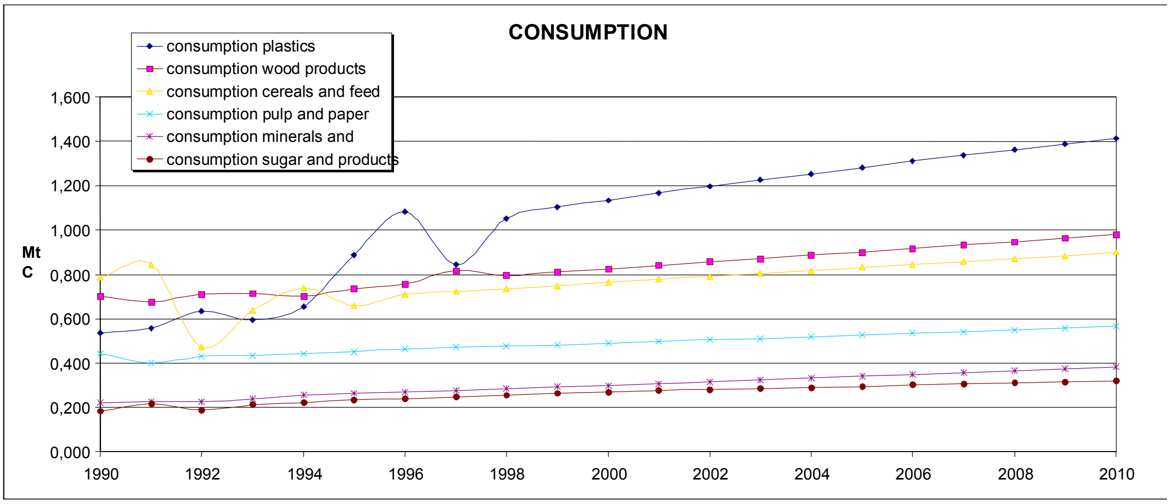
Here the assumption towards sustainability could stop the increase in the import, caused mainly by the reduction in the import of fossil products.



The total waste amounts out of the whole {PROD} module present a rather constant behavior up to 1998. The values for the years after 2000 were calculated out of the consumption flows and the coefficients for accumulation as described before. Herewith a clear increasing tendency was received, dominated by enhanced use of plastics and wood. There is rather no real difference between the two scenarios, the seeming surprise of the higher values in the sustainability scenario can be explained by the increase in wood and cereal processing and the resulting residues, which exceeded the effect of decrease in plastics (plastics are mainly imported as final products or have little waste through processing)

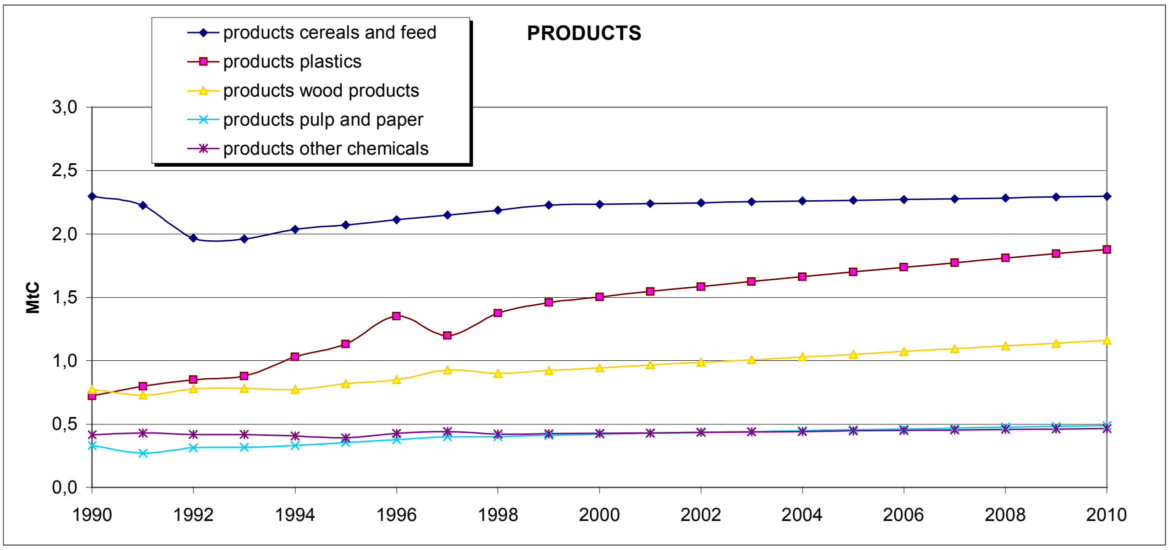
A 5-3.2 Scenario: No major changes

The main characteristic of this scenario was the continuation of the trend during the period 1990 to 1998. For some flows the inconsistency in the statistic system resulted in distortions of the development, moreover some flows showed besides that variations before or after 1995. So it was tried to derive a reasonable trend for all the flows by striving for the most likely development, this was difficult only in few cases, like plastics and cereals.

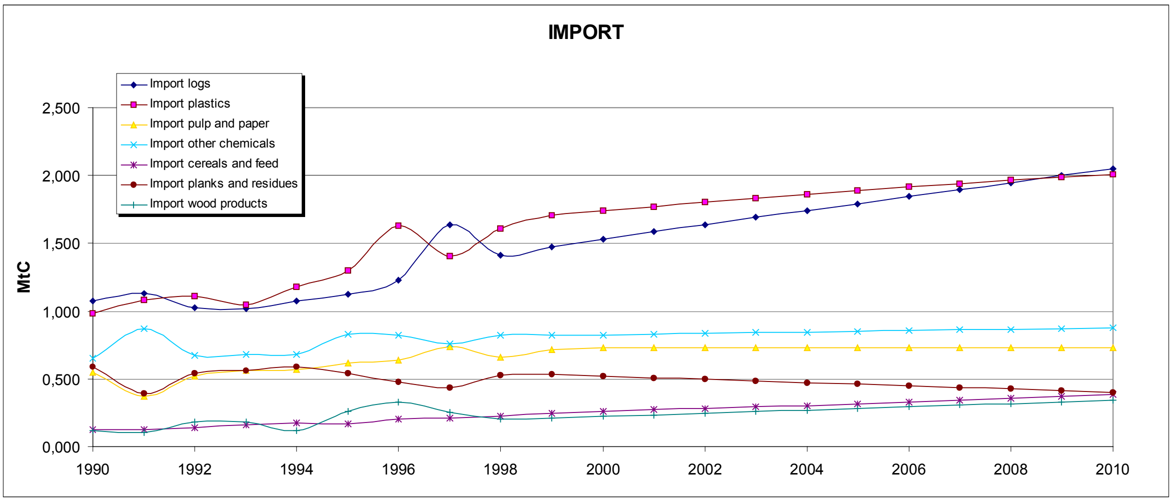


The trends in consumption present for most of the product group's slightly increasing tendency, which was continued until 2010. Difficulties arose at the plastics from the variation in last years. Here the seeming strong increase was weakened, looking at the general trend in plastic consumption in the EU countries. Despite that correction the values seem to represent rather the upper limit. Cereals show a similar variation in the first years of the regarded period, behaving up to 1998 like a damped oscillation. This made it easier to derive a trend, for which accordingly to the other products a slight increasing development was assumed.

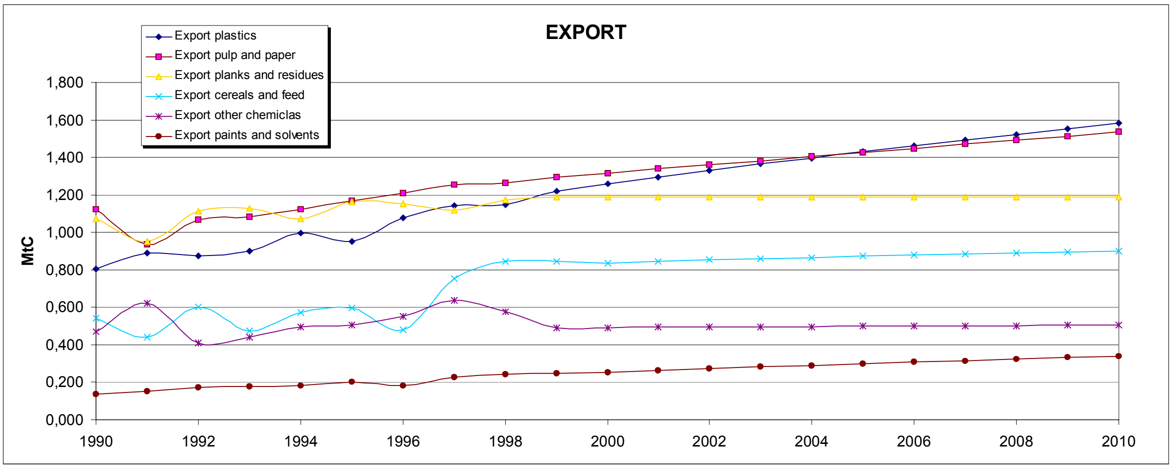
Looking at the magnitude of the carbon flows the plastics, wood and cereals are clearly dominating the situation. Pulp and paper, minerals and metals and sugar and starch have only minor relevance.



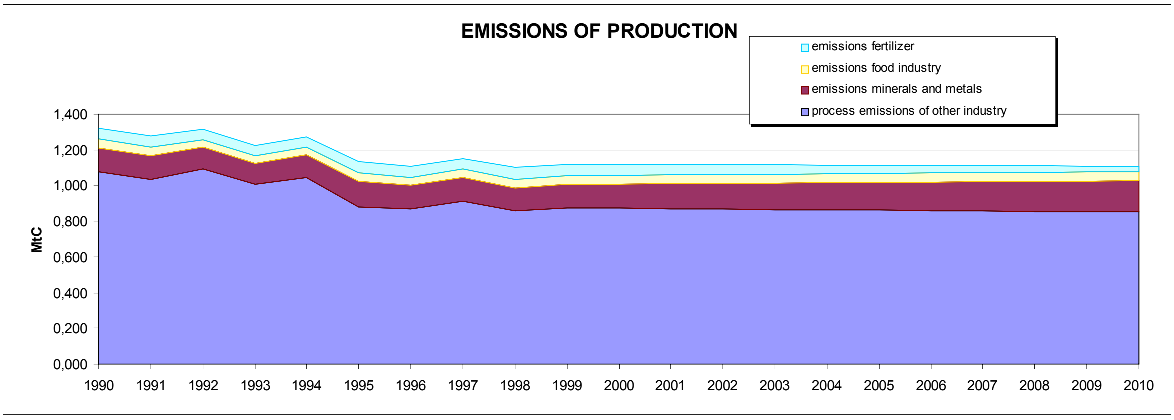
Looking at the situation in inland production one may find the same flows at important position, whereas the development is different. Cereals and feed present the highest values with rather constant behavior, whereas the plastics show the biggest increase, although the development of the last years was damped. Wood products start at the same amount as plastics and have a constant but a definite slighter increase.



In a comparison of the import flows the plastics have the highest values and show a similar trend as for production and consumption. As in production and consumption the development derived from the period 1990 to 1998 was damped. Nearly the same magnitude of the flow shows the import of wooden raw materials, namely logs, with an even higher increase than plastics up from 2000. All together the import of wood products, split in logs, planks and wood products present clearly the biggest amounts, because of the high demand for wood products and the comparably slight increase of 1% per year of wood from inland forests. The other flows behave rather constant or are of minor importance.



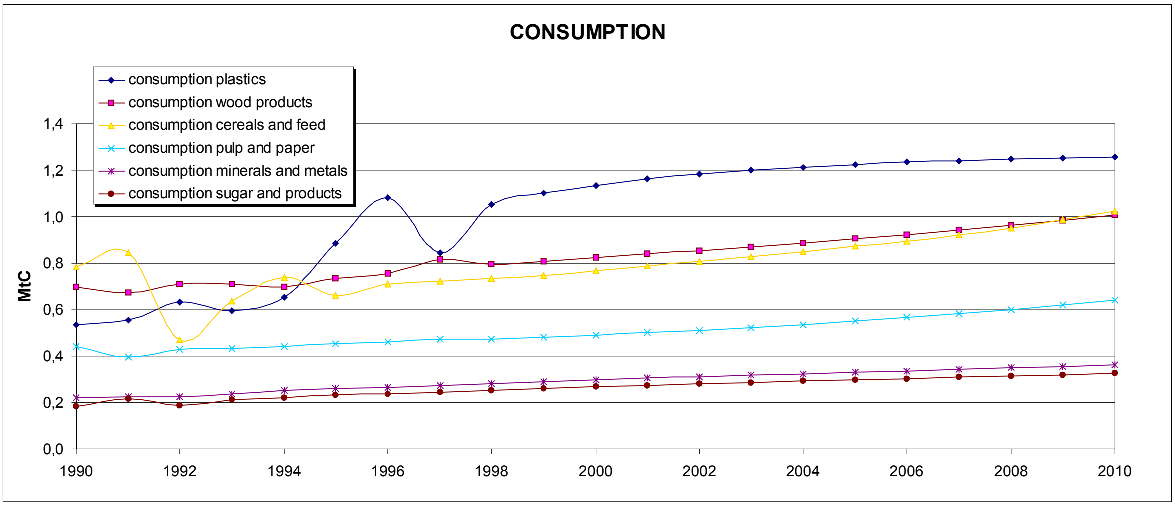
At the export flows wood products and plastics again are in dominant position. Plastics show once more the highest increase. But if the wood products were summed up they would be in clear leading position. As single position the export of pulp and paper has high values.



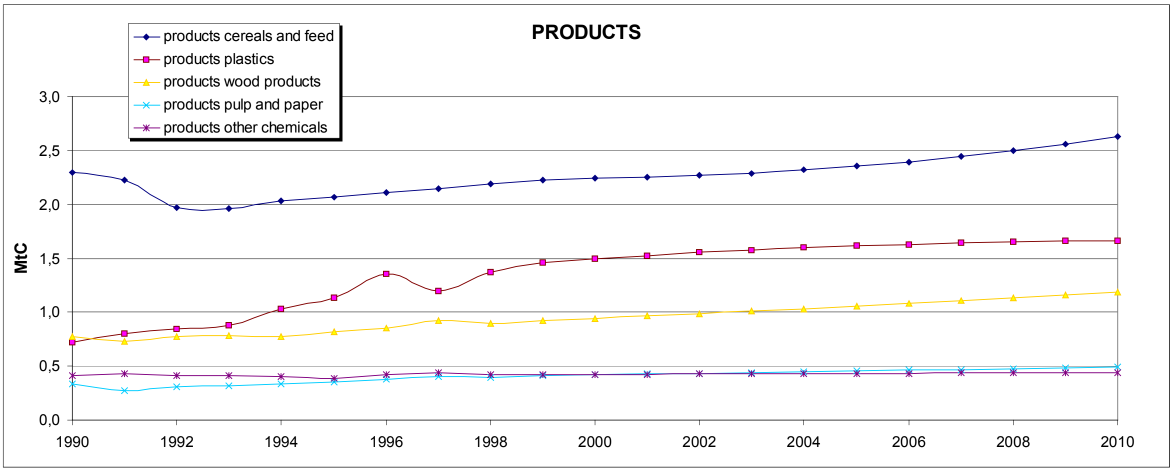
As for the emissions the processes of cement, glass and ceramic production are clearly dominating the situation. There were no DPs influencing this processes directly, so they were calculated as trends from the years 1990-1998, showing a quite decreasing tendency up to 1998, which was continued until 2010. The emissions of minerals and metals show a slight increase due to a slight increase in production of steel. The process emissions of lime production were not counted, because of a due balance of carbon-flows of the module from and to atmosphere during the lime burning and the later fixation during use.

A 5-3.3 Scenario: Towards sustainability

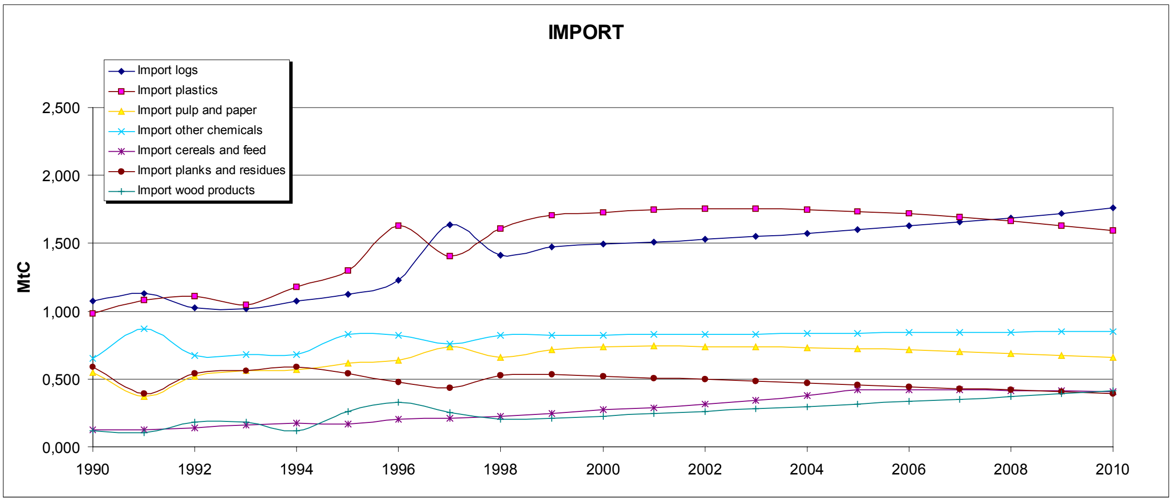
In scenario 2 it was tried to arrive at a more sustainable situation by adaptation of the relevant assumptions. This concerned mainly the reduction of use of fossils and enhanced use of renewables, as it was described under “Scenarios”.



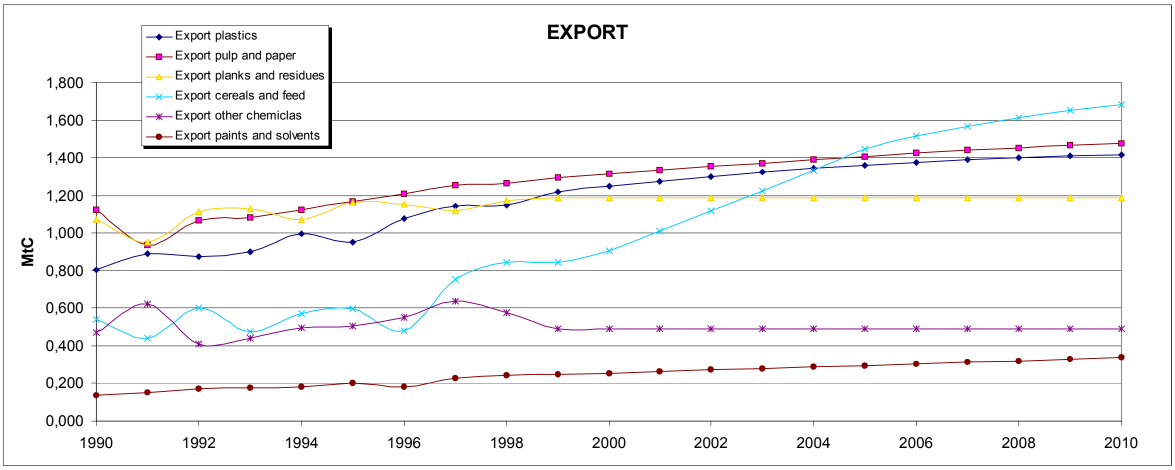
In consumption plastics are still in dominant position, although the increase was more damped than in NMC. Wood products and cereals show a steeper slope of the increase, as well as pulp and paper do. Even this cannot change the ranking by magnitude.



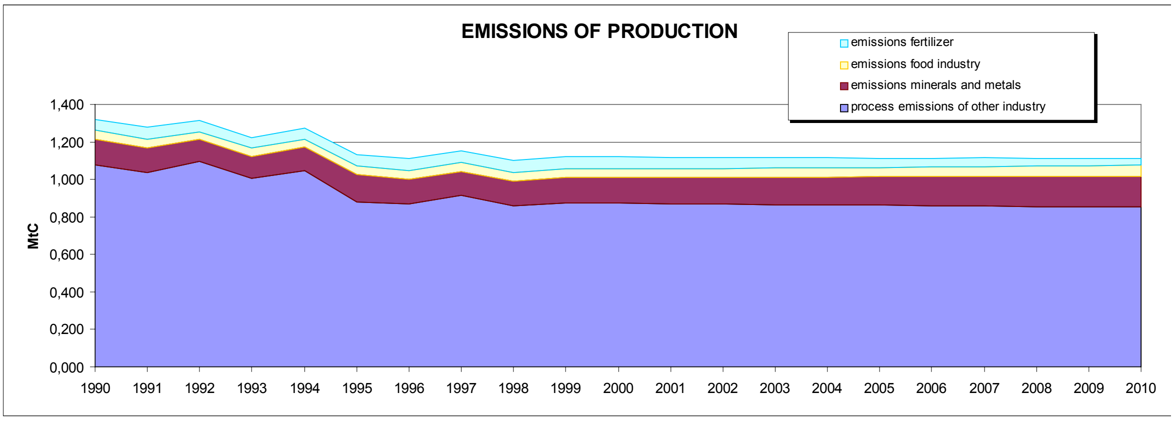
At product level the changed conditions have no remarkable effect compared to NMC scenario, the cereals remain in leading position, plastics in second and wood products in third position. The changes are only visible in the increases up from 2005, an enhanced use of wood and cereals and damped behavior for plastics, which finally leads to no changes in the positions.



More changes are visible for the imports. Here the increase of plastics import in NMC is turned to a decrease. Also import of logs is comparably lower due to enhanced forestation, as well as pulp and paper import declines due to increased inland production.



The most striking development in export flows is the sharp increase in cereals export. It is caused by the reduced husbandry and the respective implication on feed demand. As the agricultural production was enhanced the consumption alone could not cover that increase so that raised product export was the result. Plastics and pulp and paper export increase was rather damped, planks and residues arrived at constant values.



The emission situation was not really affected by the shift to more sustainable conditions, as the most important emissions appear in the {ENERGY} module.

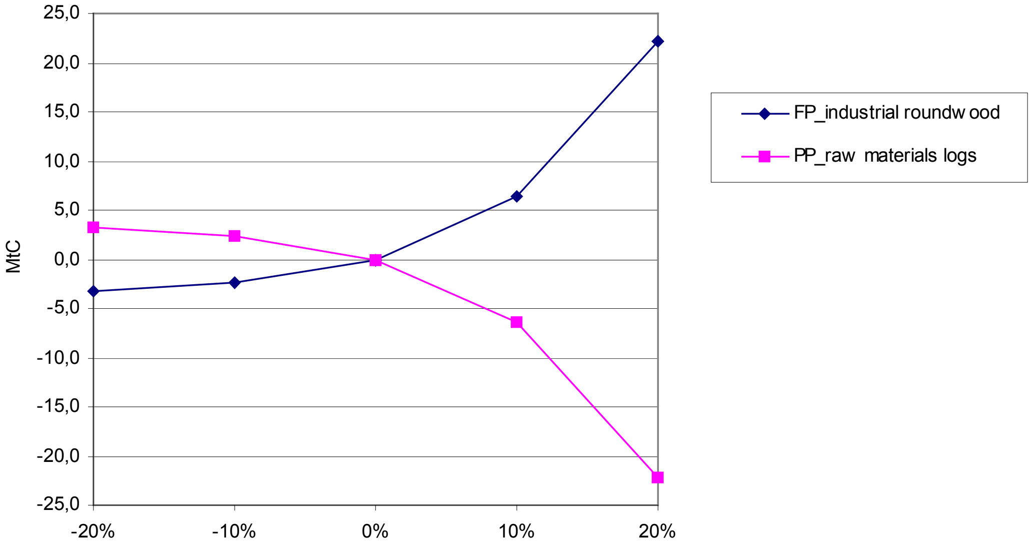
A 5-3.4 Sensitivities and Uncertainties

A 5-3.4.1 Sensitivity Analysis

The sensitivity analysis for the {PROD} Module was carried out for the most determining flows or driving parameters. These were the flow FP_industrial roundwood (wood demand from forest) and the driving parameters for the consumption and production of plastics & rubber and wood & paper. The DPs of the wood sector were varied simultaneously. FP_industrial roundwood was changed by increasing and decreasing the annual wood demand by 10 and 20 percent. Increasing and decreasing the values by 10 and 20 percent, too, varied the driving parameters. The occurred differences for Scenario 2 (TS) in amounts of Carbon in MtC are shown in the following figures for the year 2010.

As energy supply (for transformation processes and transportation) was provided by the {ENERGY} module, the emissions of the combustion processes and of the blast furnace were counted in {ENERGY}. Only the process emissions of the steel process and those of other processes were attributed to {PROD}. Due to this the sensitivity of the flows of {PROD} to atmosphere is generally not remarkable.

Figure A 5-9: Variation of wood demand for {FOREST} (FP_industrial roundwood)



The wood demand shows the highest sensitivity in the {PROD} Module. The increase of the annual wood demand of 1,2% was varied in both directions. Looking at the resulting absolute values and having in mind the realistic potential in Austria the variation produced impossible results: The Import of logs (PP_raw materials logs) showed a range from +5MtC to –22MtC compared to the Scenario results. The demand of wood has an invert behavior compared with the import of logs. We have to point out that the model runs could only be made with the {PROD} Module standing alone, because of the errors that would have occurred in the {FOREST} Module caused by the much irrational values.

Figure A 5-10: Variation of consumption wood sector

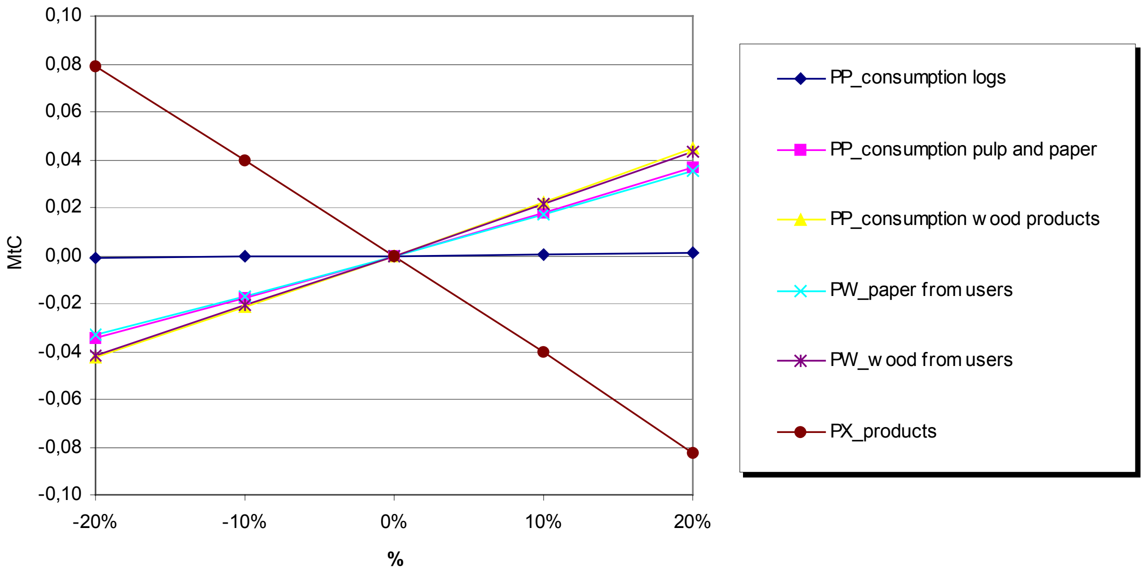


Figure A 5-10 shows the effects of the variations in the wood and paper sector. All driving parameters of the wood sector (DPP_consumption logs, DPP_consumption pulp and paper, DPP_consumption wood products) were increased or decreased simultaneously. The resulted sensitivity was rather low. The main effect occurred in export of products, but the sensitivity was too low to influence the scenario assumptions visibly.

Figure A 5-11: Variation of production wood sector

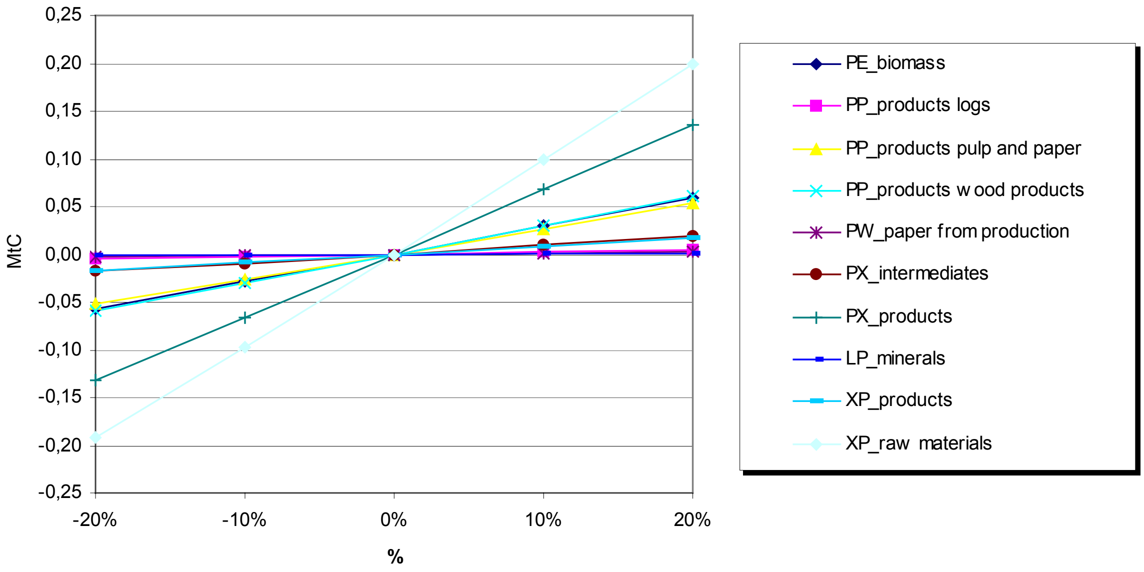
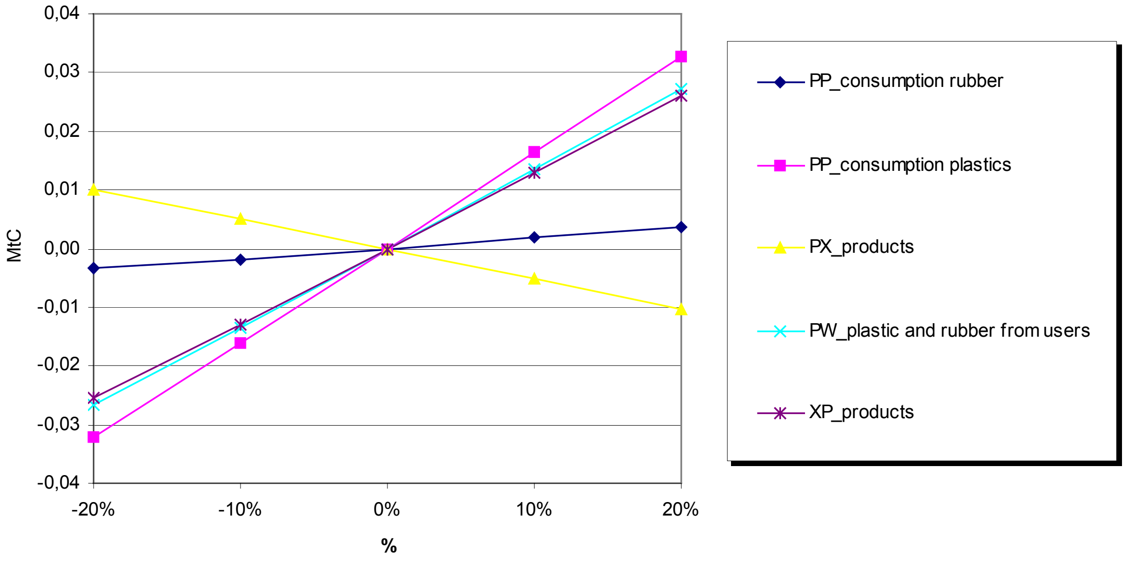


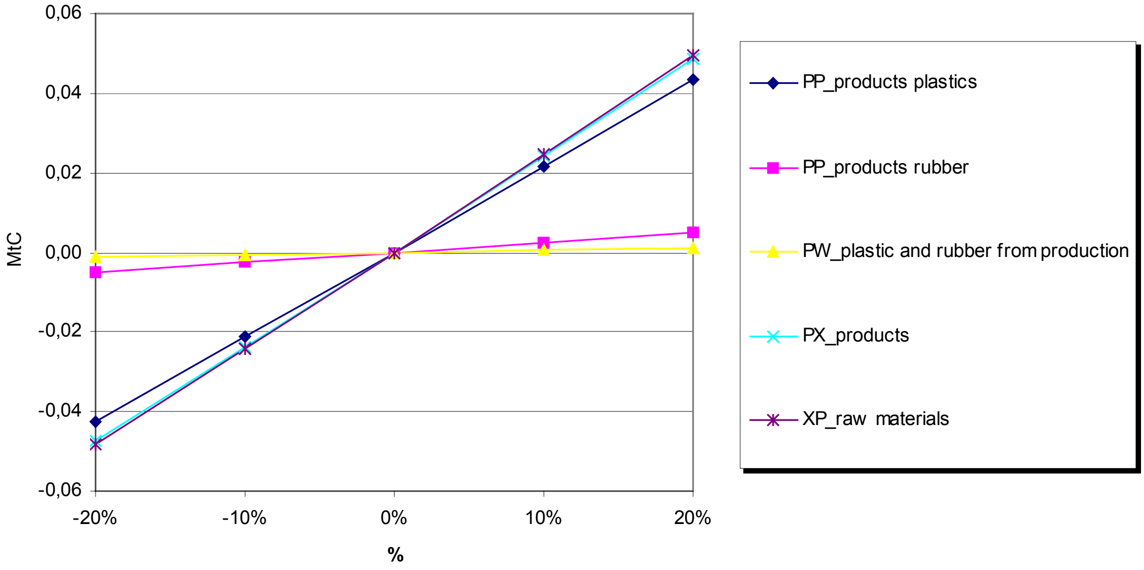
Figure A 5-11 shows the effects of the variation of the DPs for production in the wood sector (DPP_production logs, DPP_production pulp and paper, DPP_production wood products), which mainly influenced the import of products, but the effects were little, too.

Figure A 5-12: Variation of consumption plastics & rubber



In Figure A 5-12 the influence of the variation of DPP_consumption plastics and rubber on the selected parameter is shown. Once again only a low sensitivity appeared.

Figure A 5-13: Variation of production plastics & rubber



The variation of DPP_production plastics and rubber had small effects, too (Figure A 5-13).

A 5-3.4.2 Uncertainties

Whereas statistic data are generally of good quality in Austria, in many cases the information out of statistics was absolutely not sufficient to create a complete balance. Main problems were missing data or multiple counting in case of module internal process chains. To arrive at correct balances we tried to add the required information with technological background and specific knowledge.

So despite the uncertainty of statistic data, which could be quantified statistically, possible failures caused by lack of adequate information could have the most striking impact. As there does not exist an appropriate test method, we tried to check consistency of the system by balancing at different aggregation levels and comparing the flows derived from different data sources. This seemed to be the best guarantee for a realistic picture of the situation.

A lot of non physical data had to be converted, which is always a source of uncertainty. Besides, data quality in physical units obtained through national surveys is different, especially in the raw materials statistics.

One of the conclusions that should be pointed out is the need for consistent industrial physical statistics, based on better-qualified physical accounting at firm level. This means that, first, a system of physical accounting for the firms might be needed and, secondly, a homogeneous national system of physical input/output statistics should guide the first one.

A 5-4 Discussion and Conclusions

A 5-4.1 Discussion

In the NMC-scenario the plastics dominated the situation in consumption, import and export. Plastics showed the biggest increase in production, too. Wood and paper products had also high values for export. On the other hand cereals and feed dominated the product flow, as the whole agricultural production was passed through trade, even when it was consumed or exported.

The shift to a sustainable situation led to remarkable changes in production and consumption. The assumed reduction in the use and the production of products out of fossils and the contemporaneous enhancement of renewable goods led to a reduced increase of plastic consumption and production. But plastics remained still the main flow in consumption, only the increase was damped. On the other hand the consumption of wood products and the cereals and feed showed a high annual growth. The import of plastic was turned into a decrease and the import of logs could be reduced due to enhanced forestation. The cereals became the dominant export flow, caused by the reduced husbandry and the subsequently lower feed demand. The export increase was stopped for pulp and paper, caused by forced inland use. Plastics export still increased, but the increase was slower due to the reduced inland production.

A 5-4.2 Applicability of results

The simulation runs with the model for the two scenarios led mainly to changes in the dominating flows within the module, to import and export or to other modules. This concerned notably the flows of cereals, plastics and wood products.

The emissions of the {PROD} module, as it was delimited in that project, were generally not of high magnitude, as the main emissions were dealt with in the {ENERGY} module. The determining flows for greenhouse gas emissions in the {PROD} module were the process emissions of cement, glass and ceramic production. These flows showed no substantial influence of the different assumptions in the scenarios.

A 5-4.3 Priorities for future work

Priorities for improvement of the model would be in our opinion a better connection between the {ENERGY} and the {PROD} module, to show the effect of changes in the production and consumption behavior on the emissions directly. Moreover the installed pool in the consumption sub-process should be increased in its functionality to represent a realistic link between the flow of product to consumption and the waste amounts. The inclusion of life time for groups of products, how it was started but could not be finalized in that project, would allow a more serious estimation of future waste scenarios according to different product composition.

A 5-5 References

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Annex 6

ACBM Modul
WASTE

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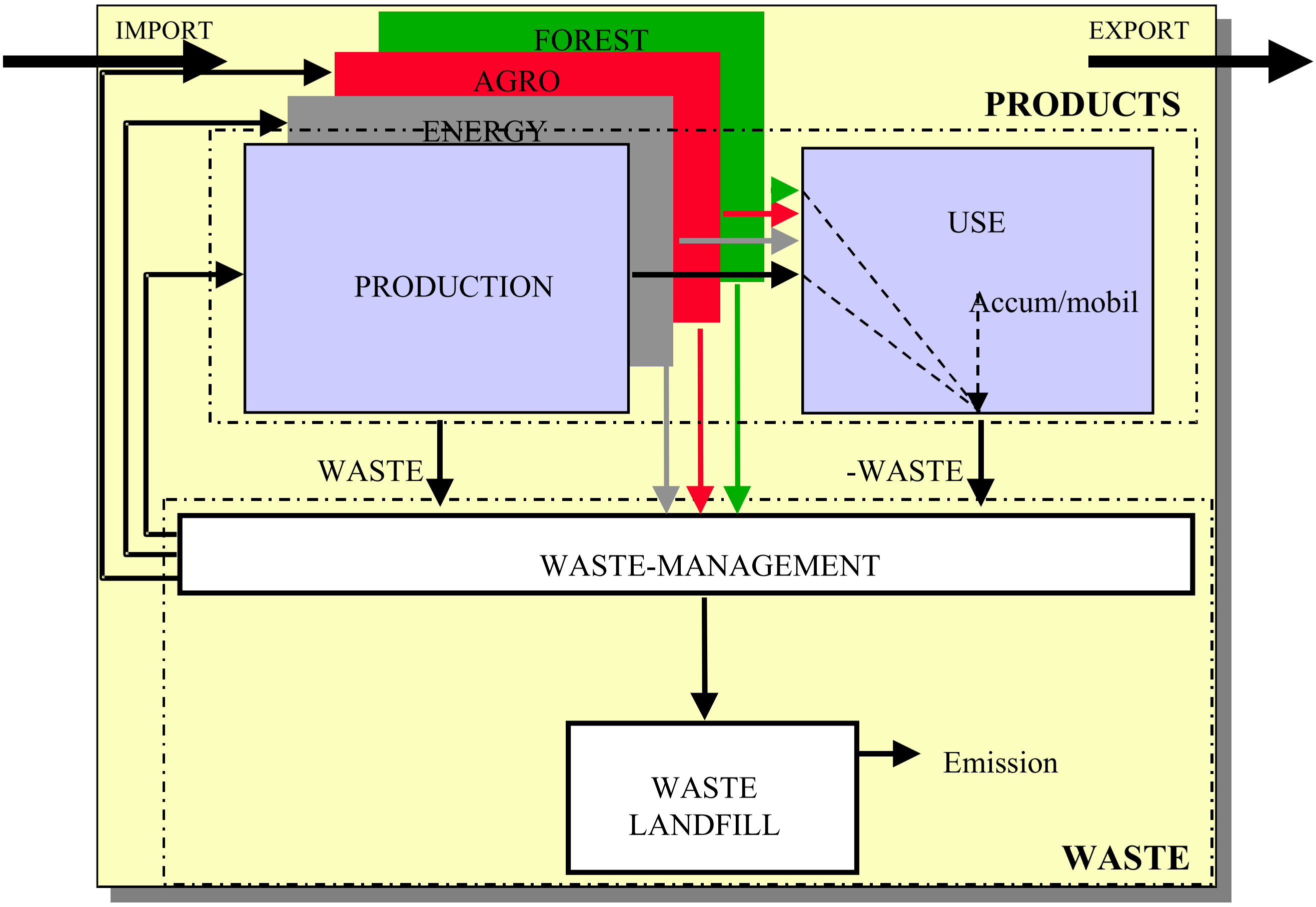
Table of Contents

A 6-1 Introduction

As the other modules the {WASTE} module has in principle connections to all the other modules, but in fact most of the inputs came mainly from the {PROD} module and here out of consumption. Outputs were directed to {ENERGY} for thermal utilization of wastes. Moreover it had also material exchange with abroad to some extent. Besides the outer connections it shows an inner structure, where it was split in waste management (collection and separation) and landfill. Of the treatment processes only water treatment and mechanical-biological treatment of wastes was regarded inside the {WASTE} module (Figure A 6-1).

Figure A 6-1: Structure and connections of the {WASTE} module



As {WASTE} was initially and is still today a typical “destination module” it had more inputs than outputs. But with the expected improvements in waste management {WASTE} turned in the scenarios more and more into a “through” module as it can be seen from the results.

A 6-2 Methodology

A 6-2.1 Data availability

The flows between the waste management subsystems were obtained from the official waste statistics. In Austria waste data is collected by Austrian Environmental Agency (“Umweltbundesamt”, UBA). This agency produces reports periodically, in which the waste flows are estimated in the context of the federal waste management plan. In addition to the 1991 report large amounts of waste data were collected within industry branch-specific pollution prevention plans (“Branchenkonzept”). Waste data are also published in different regions and local communities on a yearly basis.

Wastes are classified in Austria according to the official waste list (“Abfall Systematik”), which contains around 800 types of wastes at different levels of aggregation. Unfortunately these data are structured by waste quality category and not by waste producers. Thus the waste generated in industrial processes or industry branches could not be allocated to the list and vice versa. Furthermore, the separation between production waste and trade & distribution waste is not always clear.

With information gathered from the different sources, an appropriate waste list was established for this project that covered the waste composition, the origin, the handling and potential optimization of the waste treatment from the carbon release point of view. For all wastes the water content and the carbon content were calculated from the typical waste composition. So far waste data for 1992, 1995 and 1998 (for which the UBA reports were available) have been analyzed. The {WASTE} carbon balance has been established initially for the year 1995, then developed up to 1998 and with the data of 1992 down to 1990.

Classification of flows per waste type

All wastes were identified according to their types. Toxic wastes and non-toxic wastes were first separated in two different systems. If possible, the UBA classification scheme has been followed to ensure compatibility with official data.

Separated wastes include to a large extend paper, plastics, metals, wood and textiles. Organic wastes include collected biowaste (from households, restaurants, markets), and the biowastes that remains non-collected and is used for self-composting (“Eigenkompostierung”). Part of biowastes comes from small industries similar to households and another part from small gardens.

Building wastes include construction as well as demolition wastes (these are a mix of many materials), and wastes from road demolition, and structural timbers. Most of these wastes come from a long term use and cannot simply be linked with the amounts of production for the same year.

Residual wastes and bulky wastes are a mix of many materials. These include the residual waste from households, the bulky wastes, as well as wastes from street litter boxes.

Classification of flows per material

Each waste was also classified according to the group of material it belongs to. However some wastes are a mix that needed careful analysis. Particularly residual wastes, bulky wastes from households, construction and demolition wastes contain many different materials. They were analyzed separately to determine the amounts of different materials. A calculation of the flow per material has been available for MBT and landfills (Baumeler 1998). A new calculation was done for the composition of the remaining residual wastes, using expert judgments. Medical wastes, sludge's, and uncontrolled landfilling have not yet been taken into account.

A 6-2.2 Data and knowledge gaps

Only limited information on public level was available about prevalent types of handling of industrial wastes. Thus the team had decided to apply a default type of treatment of industrial waste. This assumption was based on data which show that handling of industrial treatment would have followed similar patterns over the last years. With the difficulties to obtain data on waste handling, there was a temptation to always choose landfill in case of missing data, but this procedure disrupted the modeling of the change induced by a new waste management policy.

Household waste handling has changed a lot since 1990. Fortunately there are sufficient data available to reflect these changes in the {WASTE} system.

The composition of each waste was difficult to obtain, in terms of materials for the mixed wastes as well as in term of organic compounds in each material. Many assumptions had to be made, but could often be improved through additional data and experiences. However, although this information was difficult to collect and compile, the parallel view of the waste system in terms of types of wastes and types of materials allowed us a better understanding of how changes in system components affect the overall system.

There were general inconsistencies of the definition of "waste" between a production point of view, and a waste management point of view. A waste flow in industry may be handled as a waste final treatment, recycled internally, recycled in the same sector, or recycled in other sectors. Internal recycling, or recycling in the same industry sector is sometimes difficult to quantify. To overcome these error sources, adjustments of the material flows were made between the {PROD} and the {WASTE} modules to avoid double counting or omitting material. Other waste specific problems like transport and energy related aspects were handled within the {ENERGY} module due to the selected structure of the modules.

No contribution was made to the actual question which waste treatment is the best as not the full range of possibilities could be checked with the model. This comparison is complicated by the different characteristic of the two processes. In incineration the carbon is released immediately to the atmosphere, the produced energy can be used. Whereas biological processes emit less CO_2 directly but none of the energy can be utilized. On the other hand they might be added to the carbon pool in soil, which plays an essential role for our life, when the composition of the produced material meets all the requirement for returning it to soil.

The frequently exercised comparisons on the basis of CO_2 emissions does not consider the carbon pool and discount CO_2 emission from biological origin. Hereby they neglect that the upstream processes (the consumption of CO_2 by the plants) does not occur at the same time as the release. So this would be fully correct only in a stationary balancing system, actually the time aspect would need to be taken into account. However this discussion can maybe become a challenging future task for the full carbon accounting model ACBM.

A 6-2.3 Model design

Our societal use of carbon is still non-cyclic to a large extent, so the waste module comes logically as the last module of ACBM. In waste management, the processes usually include collection, separation of waste, separation of mixed wastes in “Mechanical-Biological Treatment” (“MBT”), “water treatment”, “composting”, “incineration”, “recycling” processes and landfill.

In this project, we have included the separation of waste in “Waste Collection“, which is the “dispatcher” of the waste module (showed as an hexagon).

Among the process of transformation, only “MBT” and the water treatment remained as composting was assigned to the {AGRO} module, incineration to the module {ENERGY} and recycling to the {PROD} module. “MBT” included the mechanical separation and the biological treatment in one process. Transformation processes are shown as circles on the figure. Water treatment included the communal and industrial treatment process regarding the organic content. The carbon contained in the wastewater is either emitted in the atmosphere, mainly as CO_2, emitted to the Hydrosphere or joins the other wastes collected from the production and consumption processes.

If waste is not materially valorized or emitted to the atmosphere in an incineration or passed to soil after a MBT process, the carbon molecules end-up in the “landfill” were they are stored until being partially decomposed and emitted in the atmosphere. Being a storage (or sink or pool), the landfill is symbolized as a rectangle on the figures.

Connections with other modules

The flows within the waste module and the links with other modules is shown in Figure A 6-2. The {WASTE} module connects mainly with the {PROD} module. Inputs from {PROD} are industrial and household wastes that are discarded after the product lifetime. Outputs into {PROD} are waste materials (particularly separated wastes) that can be recycled in different production sectors. Organic wastes that can be composted or used directly on soils are transferred from {WASTE} into the {AGRO} module. Inputs from {AGRO} are composted materials that cannot be used there and need therefore to be disposed in landfills. Wastes that can be incinerated are transferred into the {ENERGY} module. These are either industrial wastes or residual wastes that are directly incinerated or incinerated after separation in a MBT plant. Inputs from {ENERGY} are ashes from incineration that need to be stored in landfills. There are no carbon flows between the {FOREST} and {WASTE} modules.

Import and export of wastes was considered. However, all waste materials that had a recyclable or market value were considered in the {PROD} module. Exports of recyclable wastes were first added to the flow of recyclable waste into {PROD} module and exported from there.

Emissions into the atmosphere arose mainly from the landfill pool. Landfills emit carbon in form of CO_2, CH_4 and VOC into the atmosphere. There are also minor gaseous emissions from MBT and water treatment. A part of the carbon in landfill will remain solidified and non-reactive: this carbon was regarded to be finally transferred to the lithosphere. There are also carbon flows to the hydrosphere (that is considered as a pool in the {AGRO} model).

Figure A 6-2: Carbon flows in the {WASTE} module and between {WASTE} and other modules

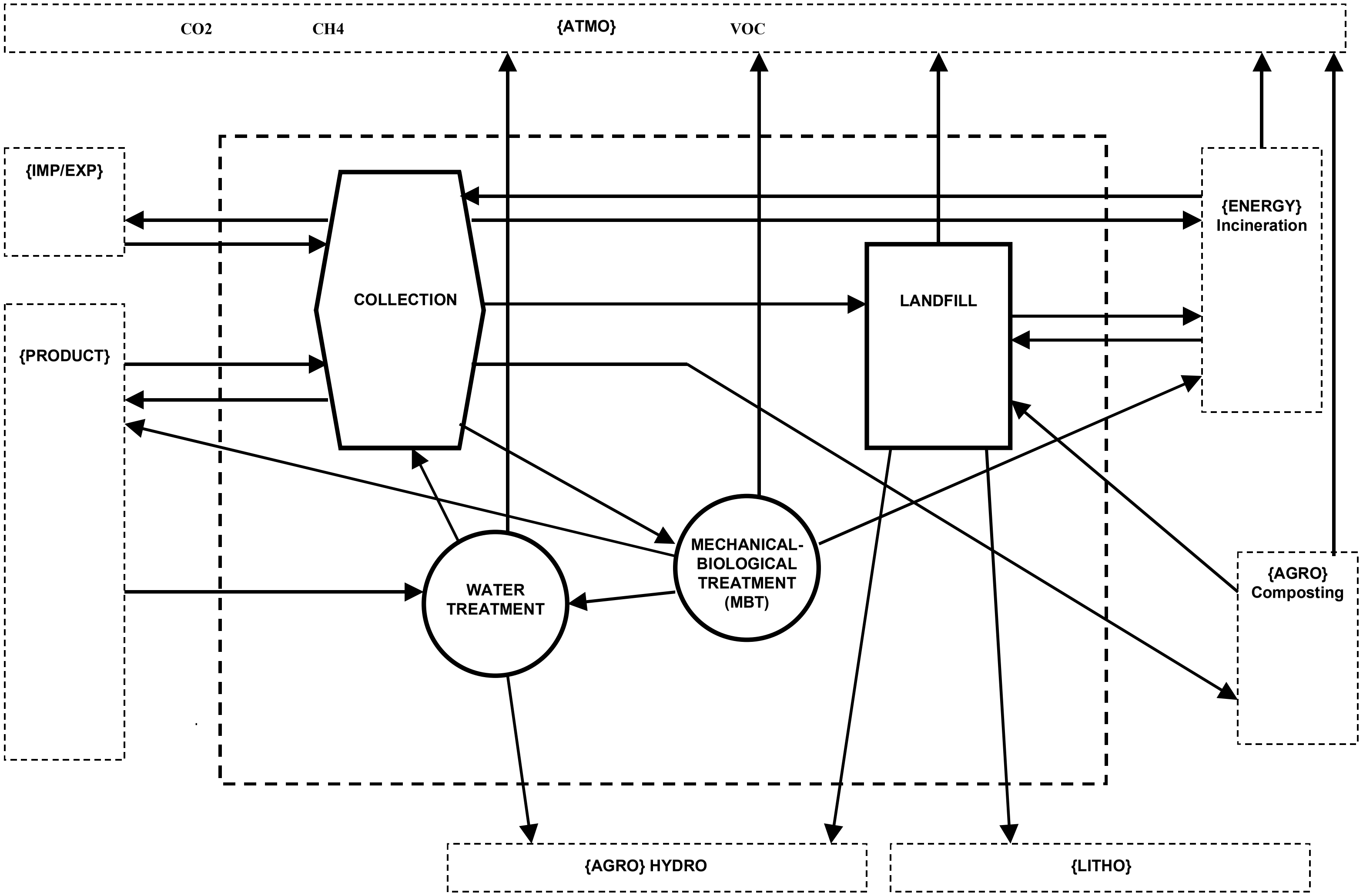
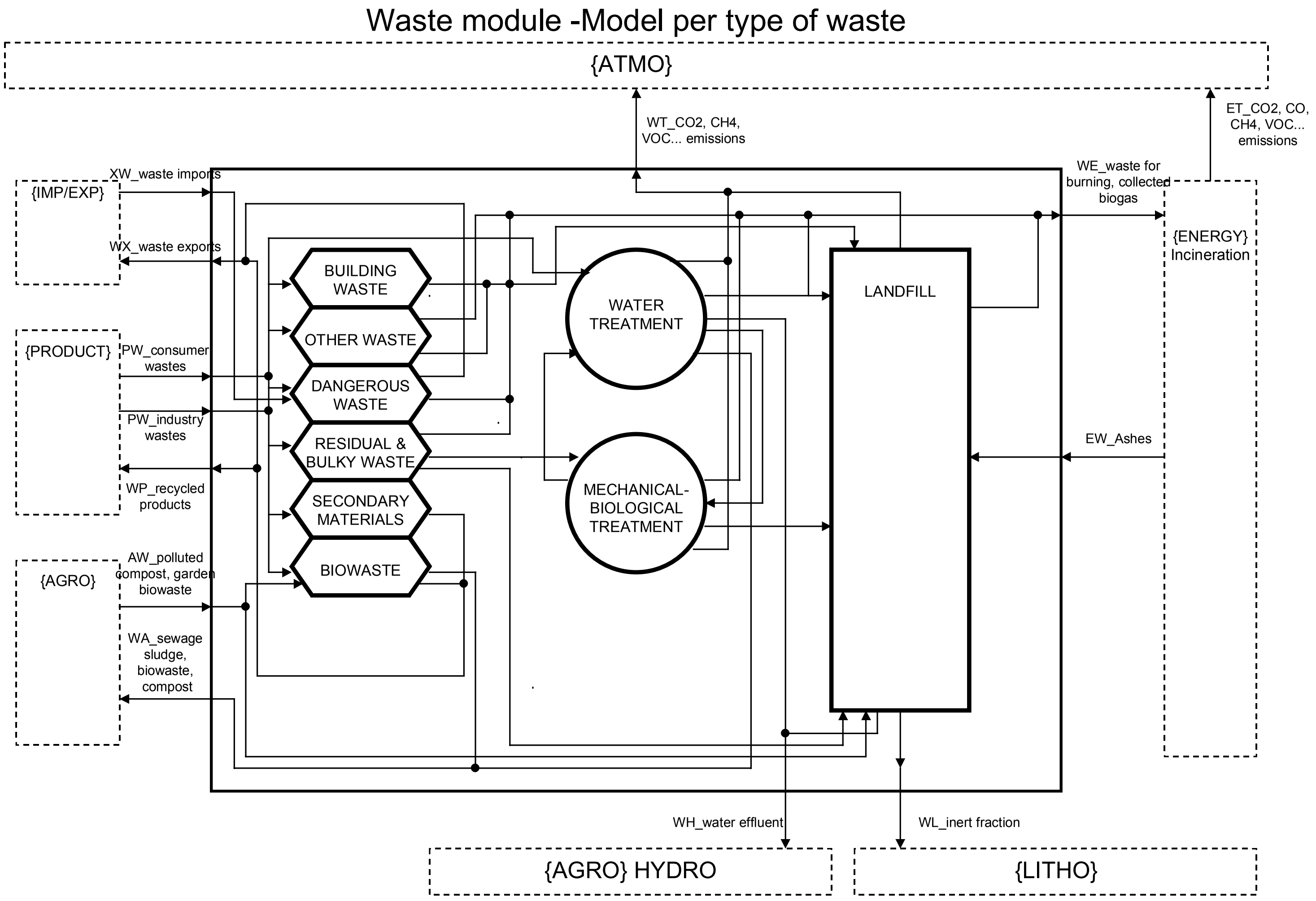


Figure A 6-3: {WASTE} module: carbon flows per type of waste



Waste types and material types

It was found that collection of information on just the carbon flows was not sufficient to understand and to model the {WASTE} module. It was necessary to have background information on the “qualities” of carbon in order to appropriately follow their fate in the waste treatment system. Thus, two parallel analyses of the waste system were made, a description “per type of waste” and one “per type of material”.

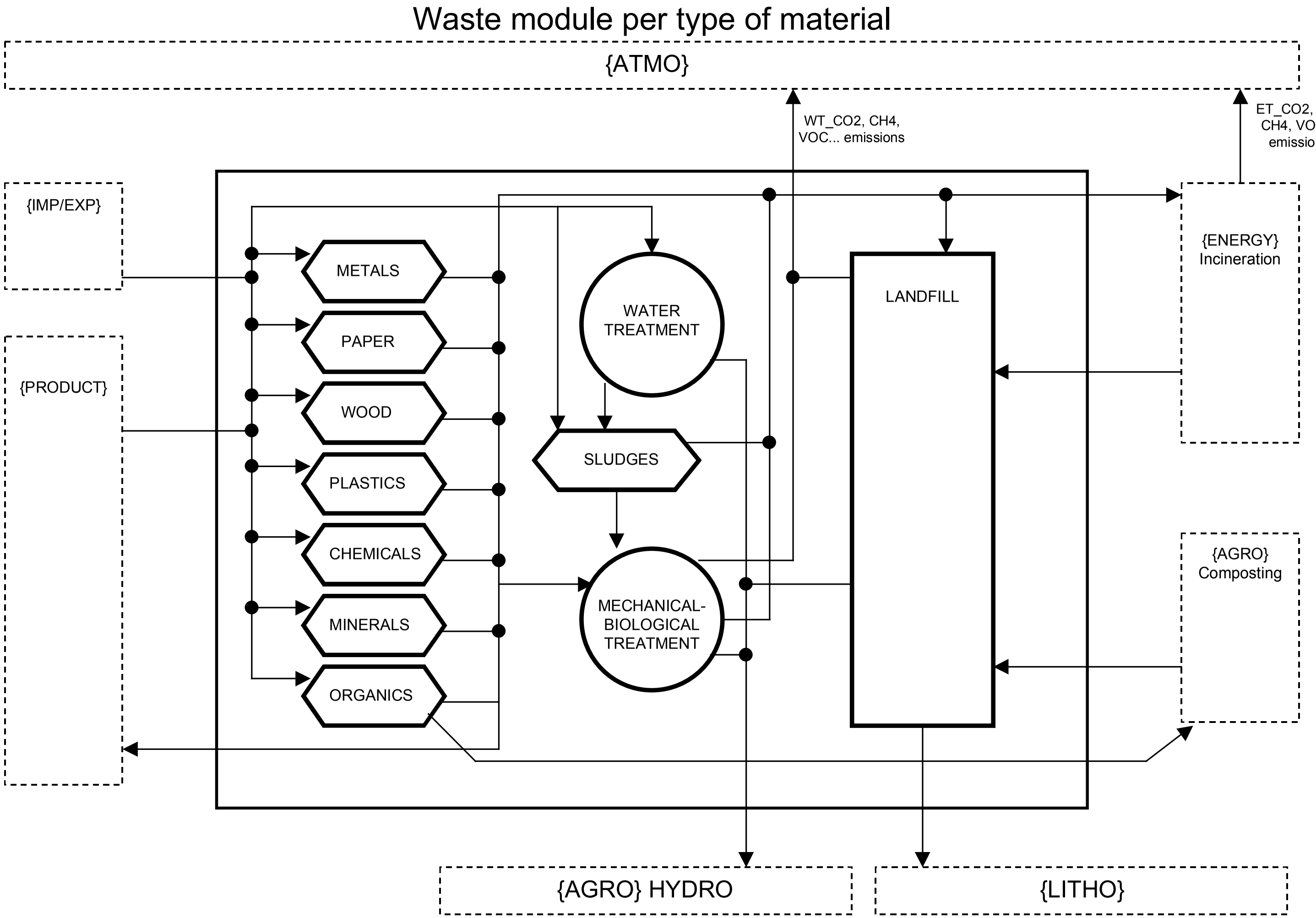
The description “per type of waste” corresponds to the common classification schemes: “Toxic Waste”, “Building Waste”, “Residual and Bulky Waste” (non-separated household wastes), “Separate Collection from Households”, and “Non-Toxic Wastes from Industry”. The main reason for using these waste categories separately was their relation with the predominant waste treatments. This information was important to understand the {WASTE} module for future scenario development. It also enabled a disaggregated view on the data, and allowed an easier understanding of the carbon flows. The types of waste also gave some indications of the recycling potential, because carbon in a highly re-usable material is certainly not the same as carbon in a mixed waste. Figure A 6 – 3 shows the waste flows for the different waste types.

Wastes represent also a mix of many materials. It is important to have information on the carbon “qualities”. In this work, “chemicals”, “paper” (includes carton), “wood”, “plastics (incl. rubber), “organic materials” and “minerals and metals” were distinguished for a number of reasons. Figure A 6 – 4 shows the waste flows for the different waste materials. First this classification enabled a link with the production of material, as material types correspond to production flows to a large extent. But it was also very important to model correctly the temporal dynamics of the MBT, incineration, and landfill processes. Sludge’s were considered as a material before being allocated to the existing groups of materials.

Moreover, information on carbon qualities gave us insight on possible optimization options, showing clearly the present inadequacy of waste treatment and the potential of recycling and reuse of valuable materials. Flows in term of carbon qualities could help to develop an improved management of materials along the waste treatment chain to avoid loosing waste material “qualities”.

With the such descriptions in terms of waste types and material types it was possible to follow the flows along in the waste treatment chain, e.g. (in terms of waste types) the treatment system for building wastes, or (in terms of waste materials) the treatment of waste paper, or (in terms of a combination of waste and material types) the treatment of paper in building wastes.

Figure A 6-4: {WASTE} module: carbon flows per type of materials



A 6-2.4 Scenarios

Driving forces

In a fully functional model the waste amounts for the future should result from consumption caused by the input flows and the lifetime. Despite the described shortcomings with lifetime in the consumption the flows to waste were determined by the {PROD} module. They were calculated from the consumption flows with a fixed proportion derived from the data of the previous years. So the main driving forces for the waste generation was located in the {PROD} module. However there remained some important changes within the waste module, which main driving forces are listed hereunder:

- the recycling rate (DPs recycling quota)
- the rates to different treatments (incineration, landfill, MBT) (DPs %incineration, %mbt, %landfilling)
- the technical improvements of the different waste treatments (DPs recycling potential, landfill gas recovery)

Transport of waste and the change in energy efficiency of incineration was dealt with within the {ENERGY} module (hereby it should be considered that incinerators in the countryside have shortcomings in heat utilization, and that they require long transport distances).

To estimate the development up from 2000, two scenarios were considered, one with "No major changes" where all factors were kept constant after 1999 and a "Towards sustainability" scenario describing more sustainable conditions.

Scenario 1: No major changes

The characteristic of Scenario 1 was the estimated business as usual philosophy, a continuation of the trends up to 1998. Therefore, the DPs were chosen in such a way that the recycling rate and recycling potential was left at the present state. The fulfillment of the “Deponie Verordnung” was considered, which does not allow the deposit of untreated waste. It was assumed here that the rate of deposited carbon will decrease to 5% until 2010 and that the waste treatment will be performed in equal shares through combustion and mechanical biological treatment (Hackl 1999). Subsequently a share of the MBT amount, the light fraction, is separated and transferred to incineration. This results in a proportion of 68 : 32 of incineration to MBT amounts after the separation of the light fraction in MBT.

Difficulties

Keeping constant the present levels of recycling rates and the recycling potential was selected because of the scenario principle to continue the present state. However it will yet come to modifications through change in awareness or new technologies. The effects of the "Deponie Verordnung" and the amount of compliance to it were based on estimates, as well as the assumed distribution between combustion and mechanically biological waste treatment. This was necessary as the final partition is still unclear.

Scenario 2: Towards sustainability

This scenario should describe a more sustainable situation in waste management compared to the business as usual. Only a few measures were needed to develop the waste module to that level, where reuse, recycling and composting play the major role. These were mainly the increase of inert materials share in landfills, avoiding the release in form of CH_4, forced collection of CH_4, and increasing the carbon content of soil with a development of composting and MBT. *Gielen (1997)* has shown the relevance of storage in products and waste for the greenhouse problem, according to this author, it is of the same order of magnitude than the positive effect of recycling and incineration. A full implementation of the Austrian landfill regulation and for waste treatment an optimized mix for the best realistic treatment for each waste was assumed.

The potentials for waste treatment improvements were obtained by going through the whole list of wastes and improving the waste management according to available literature. For residual waste treatment a combination of incineration with an improved technology of MBT (Mechanical-Biological Treatment) was assumed, as the final decision for future waste management remains a source of controversy.

The recycling performance was increased to the best level. For that the DPs were such modified that the recycling rates and potentials reached the expected maximum values.

Difficulties

It was attempted to choose the assumptions validly, however, economical aspects were only considered at the edge. This assumption that everything possible would also be carried out represent an ideal case that is maybe too to optimistic.

Definition of the chosen Driving Parameters

The DPs recycling potential were defined as the percentage of the waste amounts that could at maximum be recycled due to technical and economical preconditions. The DPs recycling rate were the percentages of waste amounts that are assumed to be recycled referring to the maximum amounts given by the recycling potentials. DPP_% landfilling took into account the “Deponieverordnung” and represented the rate of waste in percent that will be deposited untreated. The remaining waste was split into incineration and MBT, which is determined by the DPP_% mbt and DPP_% incineration. DPP_landfill gas recovery was the percentage of the CH_4 amounts emitted from landfill that was collected and incinerated in the {ENERGY} module.

The Driving Parameters are listed in Table A 6-1.

Table A 6-1: Driving parameters for module {WASTE}

Driving Force: Ecological consciousness/political support to recycling because of lifestyle

No Major Changes	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
DPW_Recycling quota textile (%)	60	60	60	60	60	60	60	60	60	60	60
DPW_Recycling quota paper (%)	89	89	89	89	89	89	89	89	89	89	89
DPW_Recycling quota wood (%)	73	73	73	73	73	73	73	73	73	73	73
DPW_Recycling quota plastic (%)	47	47	47	47	47	47	47	47	47	47	47
DPW_Recycling quota minerals (%)	81	81	81	81	81	81	81	81	81	81	81
DPW_Recycling quota organics (%)	59	59	59	59	59	59	59	59	59	59	59

Toward Sustainability	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
DPW_Recycling quota textile (%)	60	64	67	70	74	78	82	86	91	95	100
DPW_Recycling quota paper (%)	89	90	91	92	93	94	95	96	98	99	100
DPW_Recycling quota wood (%)	73	76	78	81	83	86	88	91	94	97	100
DPW_Recycling quota plastic (%)	47	51	55	59	64	69	74	80	86	93	100
DPW_Recycling quota minerals (%)	81	83	84	86	88	90	92	94	96	98	100
DPW_Recycling quota organics (%)	59	62	66	69	73	77	81	86	90	95	100

Driving Force: Economic support to recycling/Quality maintenance of materials because of economic structural change

No Major Changes	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
DPW_Recycling potential textile (%)	43	43	43	43	43	43	43	43	43	43	43
DPW_Recycling potential paper (%)	80	80	80	80	80	80	80	80	80	80	80
DPW_Recycling potential wood (%)	86	86	86	86	86	86	86	86	86	86	86
DPW_Recycling potential plastic (%)	74	74	74	74	74	74	74	74	74	74	74
DPW_Recycling potential minerals (%)	84	84	84	84	84	84	84	84	84	84	84
DPW_Recycling potential organics (%)	81	81	81	81	81	81	81	81	81	81	81

Toward Sustainability	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
DPW_Recycling potential textile (%)	43	43	44	44	45	45	46	46	47	47	48
DPW_Recycling potential paper (%)	80	80	81	81	82	82	83	83	84	84	85
DPW_Recycling potential wood (%)	86	86	87	87	88	88	89	89	90	90	91
DPW_Recycling potential plastic (%)	74	74	75	75	76	76	77	77	78	78	79
DPW_Recycling potential minerals (%)	84	84	85	85	86	86	87	87	88	88	89
DPW_Recycling potential organics (%)	81	81	82	82	83	83	84	84	85	85	86

Driving Force: Waste management because of policy

No Major Changes	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
DPW_% incineration (%)	72	67	62	58	54	50	50	50	50	50	50
DPW_% MBT (%)	28	33	38	42	46	50	50	50	50	50	50
DPW_% landfilling (%)	75	74	71	65	55	45	37	31	26	23	20

Toward Sustainability	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
DPW_% incineration (%)	72	67	62	58	54	50	50	50	50	50	50
DPW_% MBT (%)	28	33	38	42	46	50	50	50	50	50	50
DPW_% landfilling (%)	75	57	44	33	25	19	15	11	9	7	5

Driving Force: Land gas recovery because of technical development and implementation

No Major Changes	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
DPW_% of landfill gas recovery (%)	15	15	16	16	17	17	18	18	19	19	20

Toward Sustainability	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
DPW_% of landfill gas recovery (%)	15	17	19	22	24	27	31	35	39	44	50

Table A 6-2: Driving bags and driving forces used in the {WASTE} module

	NO MAJOR CHANGES (2000-2010)	**TOWARDS SUSTAINABILITY (2000-2010)**
DB ECONOMIC STRUCTURAL CHANGES	**Economy will shift from primary to tertiary sector. Increase of IT-based economy. Consumption of goods will increase. In energy sector shift from coal/oil to gas. 2 % increase per year of the area for extensive agriculture. Agricultural output remains almost the same. Cheaper world prices for electricity & increased imports of primary products, food, and feed.**	**Economy will shift from primary to tertiary sector. Increase of IT-based economy. Consumption of goods will increase. In energy sector shift from coal/oil to gas. Slowly increasing use of renewable energy sources. 4 % increase per year of the area for extensive agriculture. Agricultural output has a slight decrease due to the extensivation of agriculture.**
DF Economic support to recycling/Quality maintenance of materials	Combustion of waste will increase highly from 2004. By 2010 40 % of all wastes will be incinerated, 40 % goes to MBT	Combustion of waste will increase highly from 2004. By 2010 50 % of all wastes will be incinerated, 50 % goes to MBT.
DB LIFESTYLE	**Continuation of 1990-2000 rates of single households, environmental awareness, nutrition patterns, vehicle mileages. Increasing vehicle use for „fun" matches decreasing commuting because of teleworking.**	**Continuation of 1990-2000 trends, but less vehicle use (decrease in annual vehicle mileage by 5 % until 2010), more environmental awareness, more vegetarians. Increase of natural forests and changes of forest management strategies**
DF Ecological consciousness/political support to recycling	Continuation of current trends	Increase rate above current trend
DB POLICY	**80 % efficiency of municipal solid waste dump regulation; no achievement of Kyoto goals**	**100 % efficiency of municipal solid waste dump regulation, achievement of Kyoto goals.**
DF Wastemanagement	Increasing effectivity of regulation for wastes to 80 % in 2010. See above: Combustion of waste will increase highly from 2004. By 2010 40 % of all waste will be incinerated, 40 % goes to MBT	Increasing effectivity of regulation to 100 % for wastes until 2010. See above: Combustion of waste will increase highly from 2004. By 2010 50 % of all municipal wastes (outside Vienna) will be incinerated, 50 % goes to MBT
DB TECHNICAL DEVELOPMENT	**Continuation of current trends**	**Increased efficiencies above current trends**
DF Recovery of landfill gas	Recovery rates of 10 % by 2010	Recovery rates of 50 % by 2010

A 6-2.5 Model Formulation

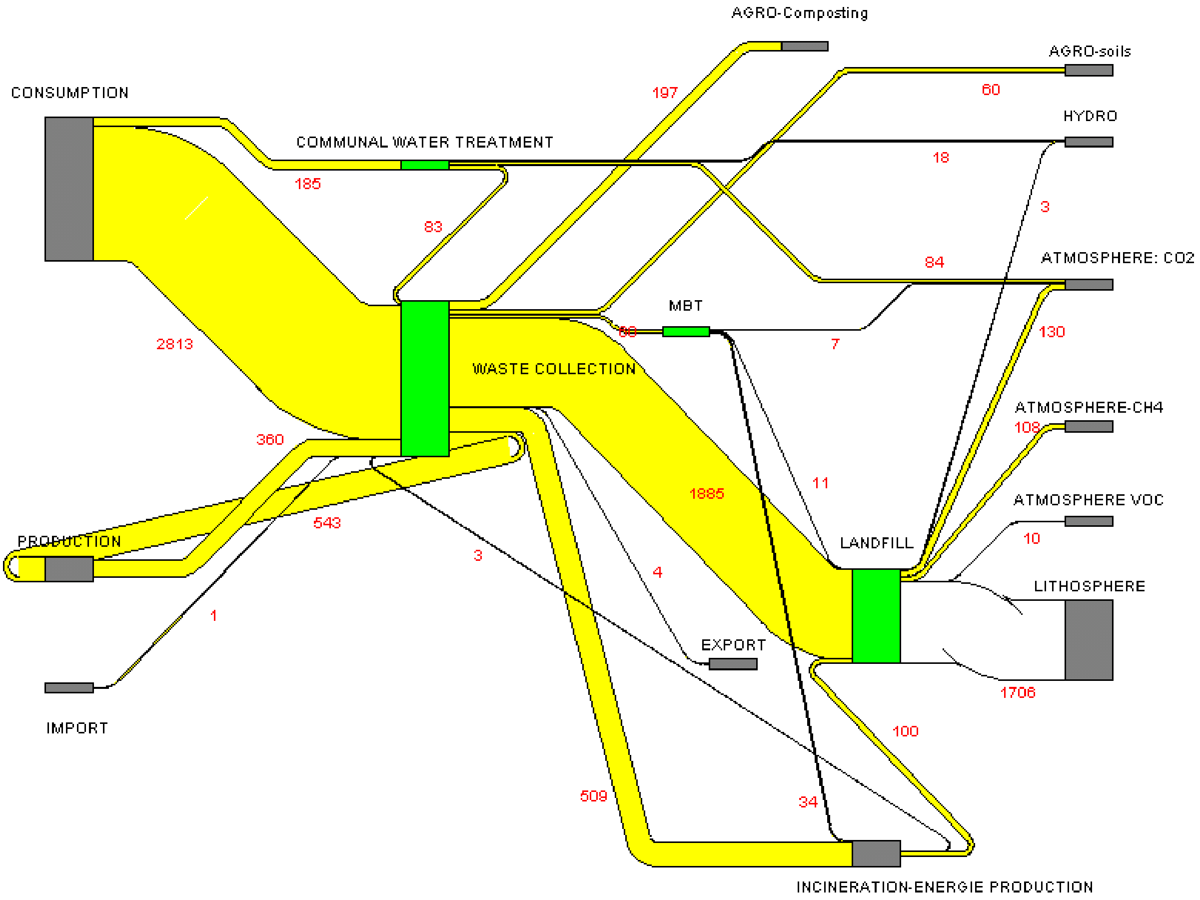
For the period 1990 to 1998, the waste module was established according to the official UBA data. A theoretical function based model was developed for the MBT process and for landfill emissions to guarantee a consistent continuation of the emission development in the scenarios. For these processes the waste composition was needed to be taken into account. This was important because the degradation and the gasification processes differ considerably between the different materials. It is anticipated that waste flows will change considerably in the future: Plastic material will replace many metal and mineral materials, which should be included (e.g. plastic bottles). On the other hand, the effect of legislation that aims at increasing the use of renewable raw materials and that cuts landfilling of organic material should be described with the model.

Very stable materials like plastics and lignin (from wood) were considered as non-degradable in the context of this study. They represent a carbon storage. This is appropriate for this study because the time frame does not go beyond the year 2010. However, the problem of stable material should be addressed if longer time frames are considered. For the different time scales of the degradation of waste materials and the gasification into CO_2 and CH_4 see Table A 6-3.

Table A 6-3: Rate of degradation of materials depending on the time scale considered and share of CO_2 and CH_4 in air emissions (Björklund 1998)

	20 years (%)	**100 years (%)**	**CO_2 (%)**	**CH_4 (%)**
Lignin	0	0	0	0
Cellulose/hemicellulose	50	70	59	41
Easy carbohydrates	100	100	50	50
Fats	100	100	28	72
Proteins	100	100	49	51

Figure A 6-5: Flow diagram in the waste module for the mix of all materials, all values are in Kilotons of carbon (KtC) in 1995. Grey processes are not in the waste module. The flow from landfill to lithosphere is shown in white, because it is dependent on the time scale chosen, which is here 20 years.



VBA Modeling

From 1990 up to 1998, data was read from the database, the year 1999 was extrapolated from the available data. The most important flows in the module {WASTE} were the amounts of waste, which were determined by the other modules. The different processing schemes of the waste were controlled via the Driving Parameters.

All flows into the module were summarized in the process waste collection according to different waste qualities and then split into recycling, incineration, MBT and landfill. This distribution occurred on the basis of the preconditions of the DPs. The carbon amounts contained in wastewater were shared with partition coefficients among sludge, emissions and water effluent, which were derived from the last years. The water effluent was delivered to {AGRO}, the sludge’s were assumed to be passed to combustion, landfill, MBT and {AGRO}.

The processing of the waste in the MBT and the resulting flows to incineration and landfill (and in future maybe to soil) was calculated with a partition coefficient, which was determined from the last years. Having in mind the actual situation, where MBT product is mostly used for landfill covering, no significant flow of MBT product was installed. In the waste collection of minerals and metals a recycling was considered. The emissions were calculated proportionally to the content of organic waste.

The waste for incineration was delivered to {ENERGY}, the combustion ash came then back from {ENERGY} in the following year.

The flows going to Landfill were divided according to the content of organic and inorganic carbon. The inorganic carbon was regarded as inactive and formed a flow to {LITHO} (no more reactive mass). Dump gasification was calculated from the organic carbon content (see below). A DP determined the amount of collected landfill gas and the part that was incinerated. The methane share in the landfill gas was assumed with 53 Vol%.

Calculation of landfill gas:

For the calculation of the landfill gas production the model of Tabasaran/Rettenberger (Steinlechner et al. 1994) was used:

$$G_t = 1{,}868 * C_{org} * (0{,}014 * T + 0{,}28) * (1 - 10^{-kt}) \quad [m^3/t_{WASTE}]$$

$k = 0{,}04$, $T = 30$

G_t = amount of gas formed in the period t $[m^3/t_{waste}]$

T ... temperature [°C]

t ... time in years

k ... disassembly constant [1/year]

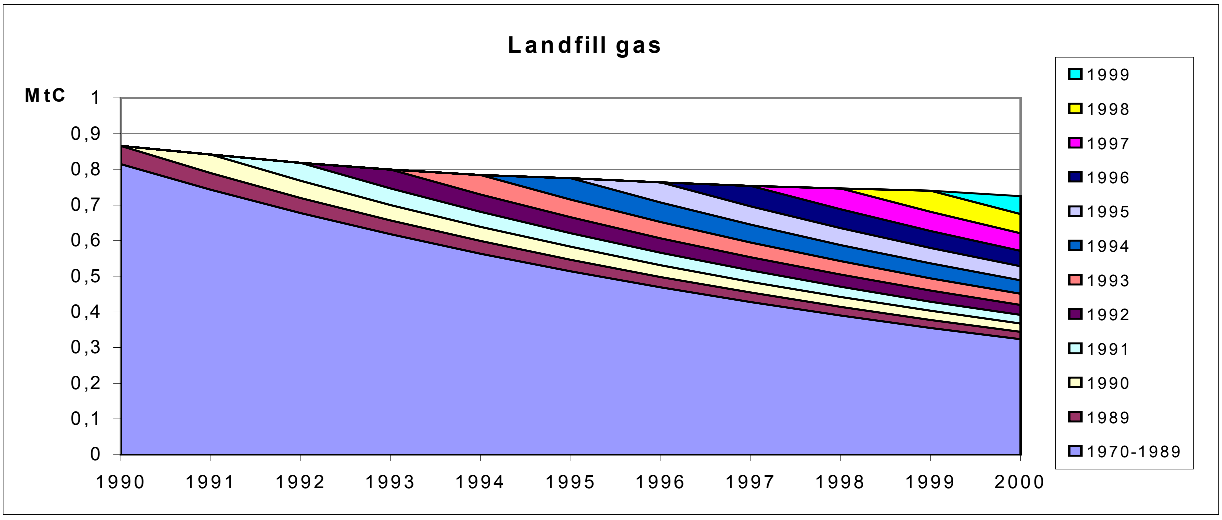
C_{org} ... Content of organic carbon $[kg/t_{waste}]$

1,868 ... Constant factor which indicates the gas volume from gasification of 1kg carbon.

Because of the definite relevance of the emissions from waste deposited before 1990 in the landfill, the waste amounts deposited since 1970 were considered. For that calculation it was assumed that 1/3 of the waste consisted of carbon and 2/3 of this was from organic origin. This organic share produced landfill gas for about 20 years in decreasing behavior according to the function above. The resulting gas amounts were calculated for the yearly waste amounts up to 2020, and then summed up for the same years between 1990 and 2010.

Figure A 6-6 shows the results of the calculation.

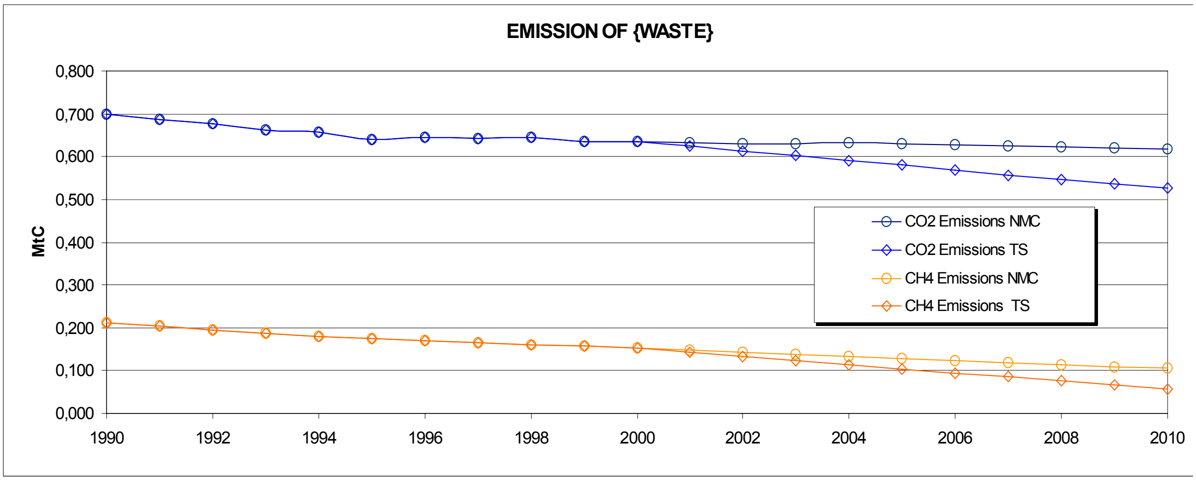
Figure A 6-6: Emissions of landfill calculated with the model of Tabasaran/Rettenberger



A 6-3 Results

A 6-3.1 Dynamic model behavior

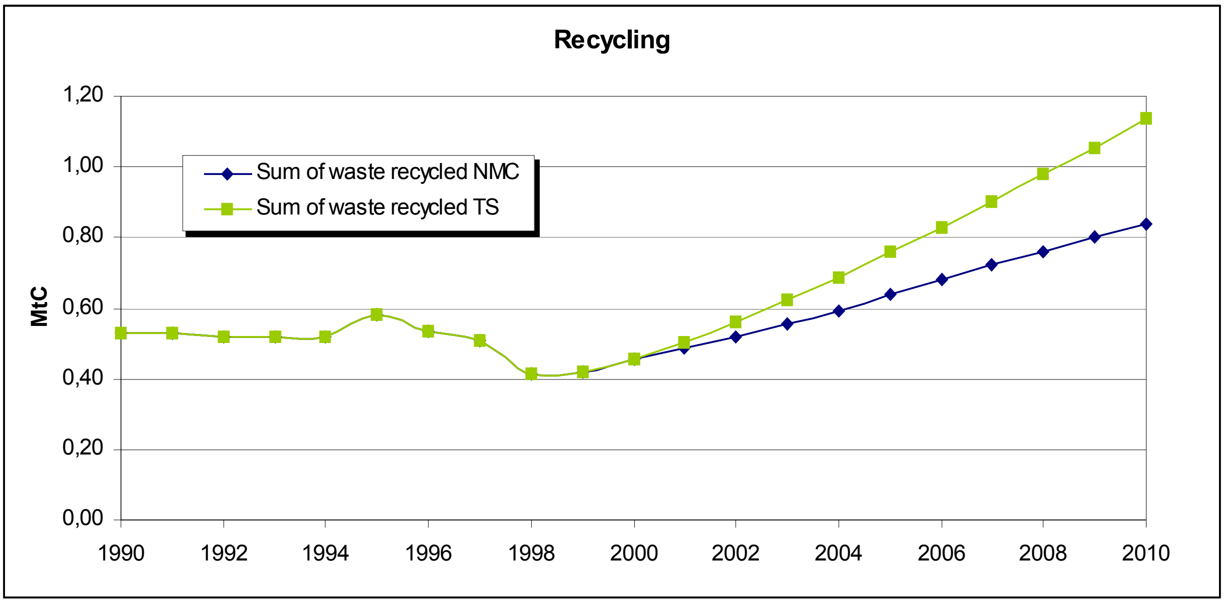
In the following figures the general dynamic behavior of the {WASTE} module and the differences between the two scenarios are outlined. The development of the total flows in the scenarios (NMC = no major changes, TS = towards sustainability) is compared for emission, recycling and the landfill pool.



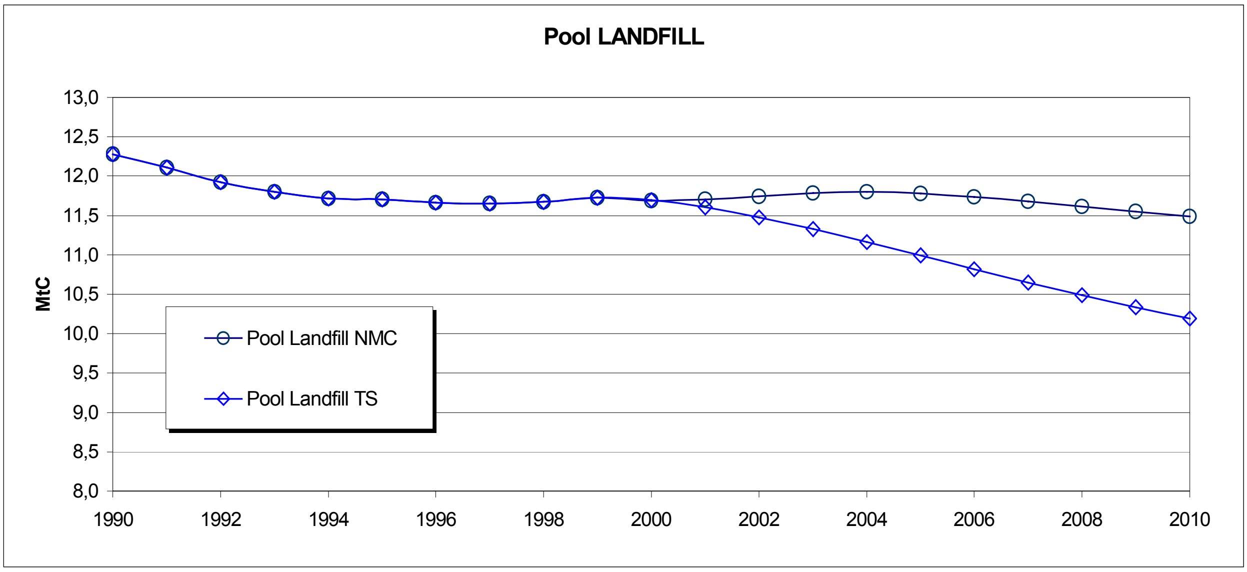
As the emissions are given in Mt of carbon and not in CO_2 equivalents (global warming units) the CO_2 emissions show the higher magnitude, whereas the CH_4 emissions would dominate the climate relevance.

The CO_2-emissions show a slight decrease over the whole time period as only the waste management, MBT and water treatment were included in the {WASTE} module, whereas incineration was dealt with in {ENERGY}. In case of no major changes the values remain rather constant up from 1995. In contrary sustainability scenario presents a stronger decline caused by the assumption of a stricter compliance to the landfill regulation. This is affected mainly by the drop of emission from wood and wood based products, which are transferred to incineration in {ENERGY} module and the emissions are consequently counted there. Moreover landfilled chemicals are phased out, too. On the other hand TS scenario increases CO_2-emissions due to the increase in the treated amounts, but the effect is not visible as only MBA is relevant here.

The CH_4-emissions show similar behavior like CO_2 due to the similar effects. Additionally the landfill gas recovery that is affected by the DPP_landfill gas recovery is higher in the Scenario TS. This collected gas is used for incineration in the {ENERGY} module, so the resulting CO_2 emissions are counted there.



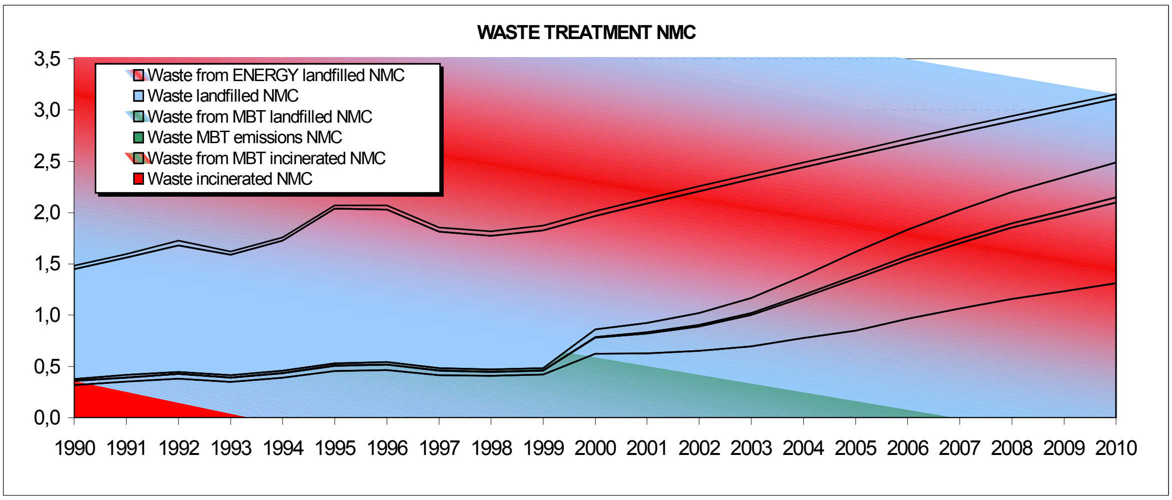
The recycled amounts show in both scenarios a clear increasing trend. The stronger increase in TS scenario results from the assumed higher recycling potentials (DPs recycling potential) and higher recycling rates (DPs recycling quota).



There was no data available for the initial content in the landfill pool. So it was calculated to 12,5 MtC at 1990 from the average of the landfilled waste since 1970 (Steinlechner et al, 1994), reduced by the emissions since then. Up from 1990 the landfill pool shows initially a decrease, which stabilizes 1995. The landfill regulation causes in both scenarios again a decline, but with quite different effect concerning time behavior and magnitude. Due to the stricter implementation in TS scenario the decrease is substantially sharper than for NMC.

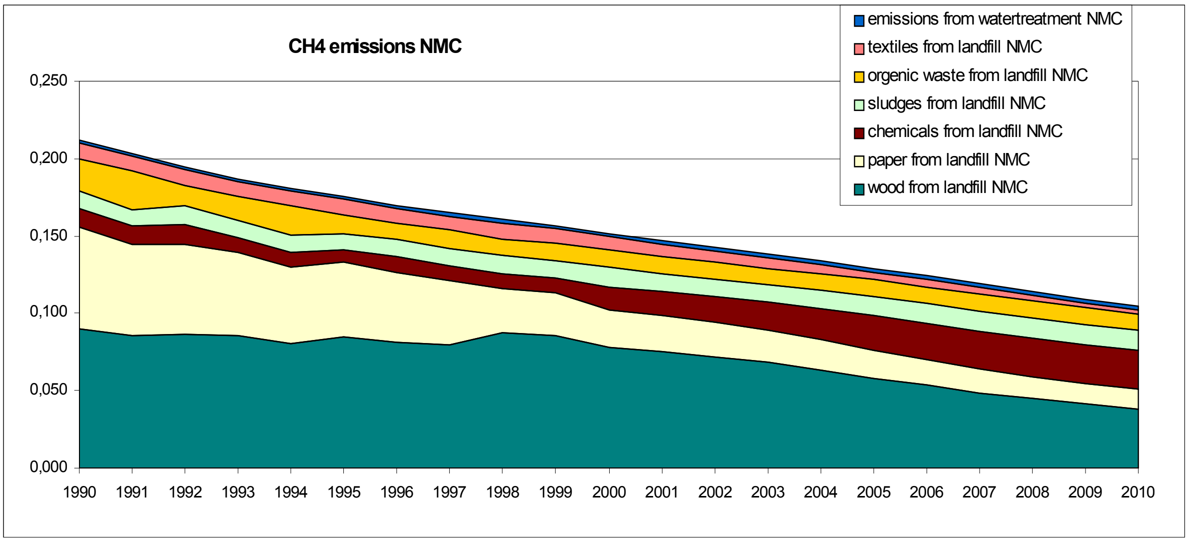
A 6-3.2 Scenario: No major changes

The main characteristic of this scenario was the continuation of the trend during the period 1990 to 1998. So despite the implementation of the landfill regulation, which results in severe changes of the situation, the business as usual philosophy was applied for the other flows and the partitions.

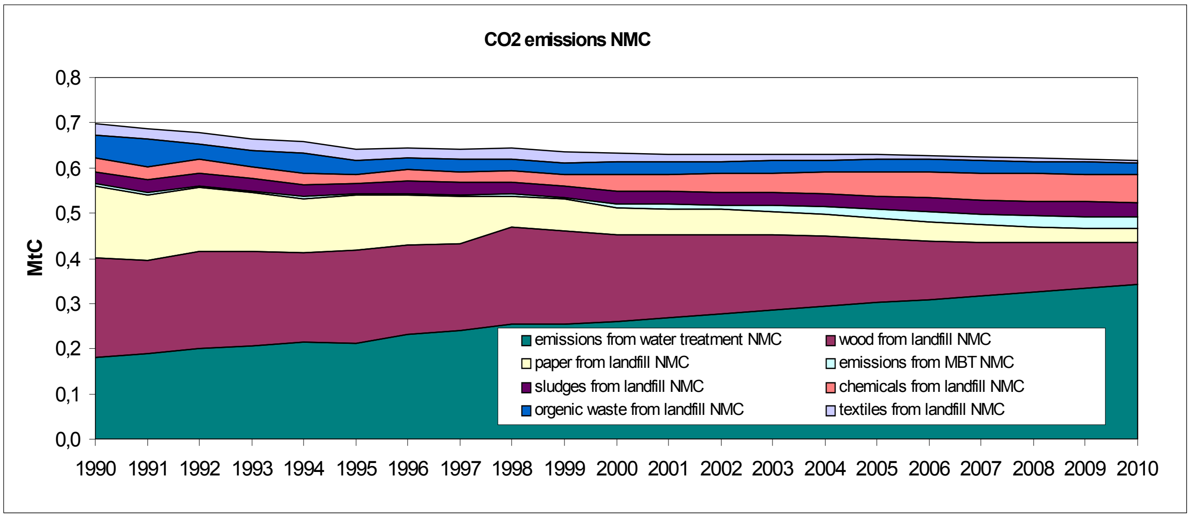


The figure above describes on one hand the development of the waste amounts, on the other hand the assumed variations in waste treatment in future. As the waste treatment represents to some respects a process chain – a part of the MBT waste goes to incineration, ash from incineration is landfilled - the cumulation of the amounts passing the different treatment installations are higher than the sum of the total waste amounts. To give a realistic unambiguous picture these double processed amounts like “waste from MBT incinerated”, “waste from MBT landfilled” and “waste from {ENERGY} landfilled” are shown separately in the areas and both colors. Then it is visible that the share of not treated waste to landfill is clearly decreasing.

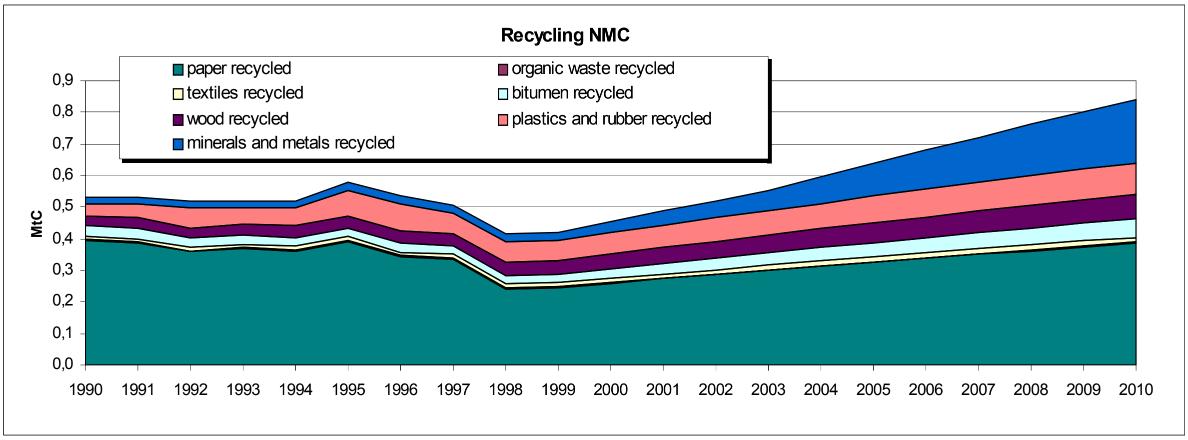
Looking at the total amounts there is still an increase also up from 2000, but the shares of the treatment systems change remarkably. MBA and incineration become more and more dominating, the relation among them is determined by the chosen mix of 50 : 50, as no final decision about the future waste management has been made.



The CH_4 emissions of WASTE module are clearly decreasing, although the waste amounts have increased. The main reasons for that development are the reduction of landfilling of untreated waste (DP: waste management) and utilization of landfill gas (DP: landfill gas recovery). The type and partition of MBT and incineration should have lesser effect on the CH_4 emission of the {WASTE} module.



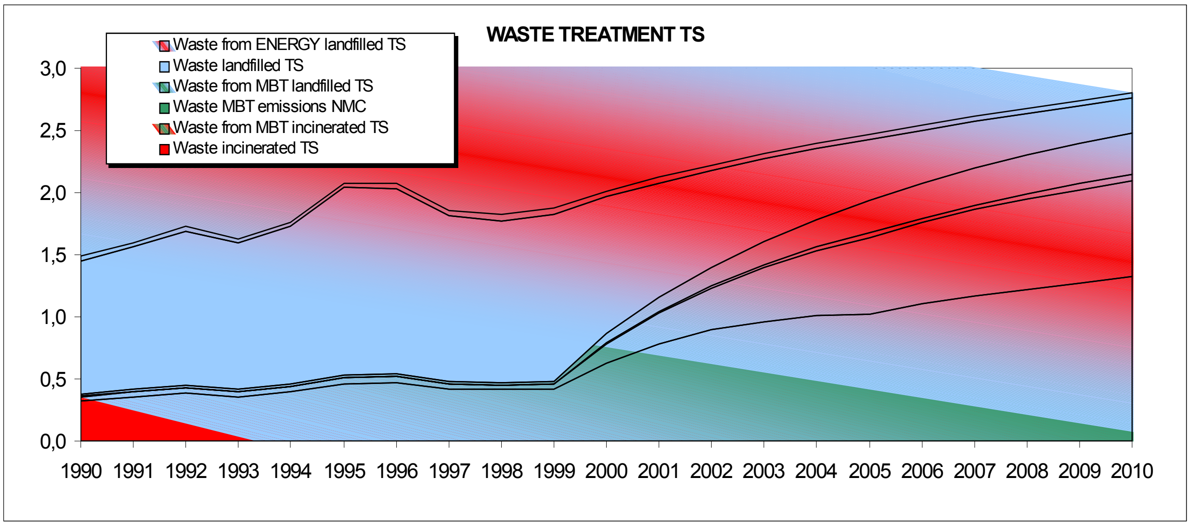
The CO_2 emissions show a decrease as well, whereas the slope is not so high. Once again we have to underline the special configuration of the modules, the incineration and their emissions were counted in {ENERGY}, which must be kept in mind. So a forced incineration will have clear positive results in {WASTE} module, as the emissions of MBT drop, but for a realistic comparison the emissions arising in {ENERGY} have also to be taken into account. Up to 2010 the emissions from wastewater treatment gain a more and more prominent position, supported by the increase in water consumption and treatment efficiency.



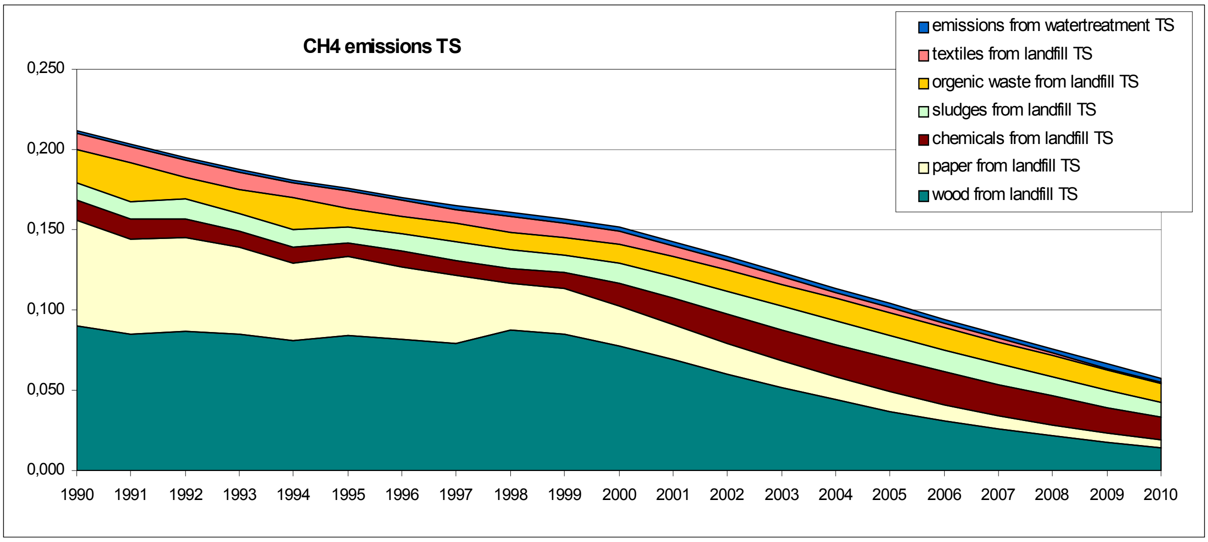
The recycling situation is generally dominated by paper products from 1995 to 1998 a decline in the amounts is visible. Although the scenario was calculated with constant recycling coefficients and potential, the recycled amounts of nearly all materials are increasing up from 2000. This is caused by the increase in the waste amounts for the single materials.

A 6-3.3 Scenario: Towards sustainability

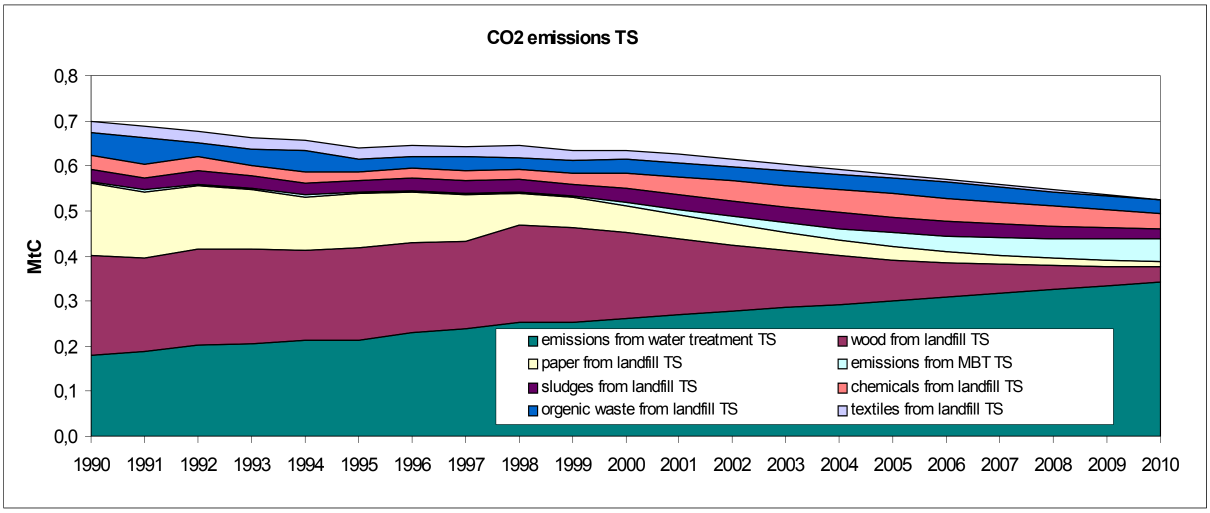
This scenario describes a more sustainable situation in waste management where reuse, recycling and composting play the major role. A full implementation of the landfill regulation and an optimized mix for the best realistic treatment for each waste are the main principles.



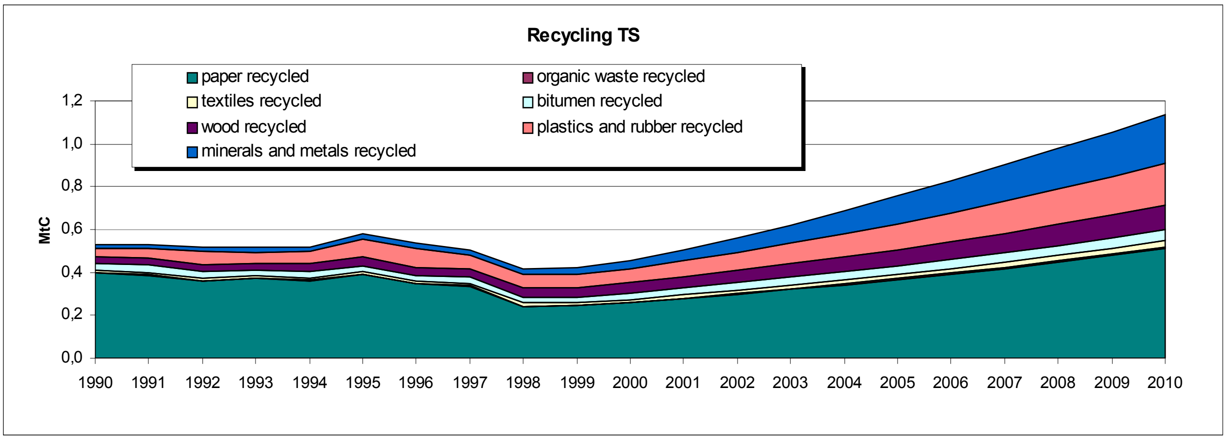
The figure above, describing the situation in waste Treatment, has the same characteristic as in the previous scenario. The development in the total amounts of waste is rather similar to “no major change”. The effects of increased recycling are more than outweighed by increasing waste from renewable products. But the most relevant change appears in the amounts processed by the different waste treatment methods. Due to the stricter implementation of the landfill regulation, banning the landfilling of waste with gaseous potential (described by the Driving Force waste management), the amounts of treated wastes rise sharply. This leads to a much faster reduction of the direct landfilling.



Consequent to the explanations above the CH_4 emissions are reduced faster, as it is aimed at in the Austrian Landfill regulation. Main pillars for that are the respective changes in DP: waste management and increased utilization of landfill gas (DP: landfill gas recovery).



At the CO_2 emissions we see once again similar effects of the described changes. The stricter application of treatment for all wastes leads to a faster and more substantial reduction of CO_2 emissions, so that the water treatment gains a dominant position. All single emissions are reduced up from 2000, except those of MBT due to the enhanced processing. On the other hand the emissions of incineration are not covered in {WASTE} module due to the described configuration of the modules.



The recycled amounts are generally higher than the previous scenario as maximum recycling was striven for. But the situation is influenced also by assumptions in the {PROD} module, which led to lower consumption of metals and plastics and affected also the recycled amounts of that materials.

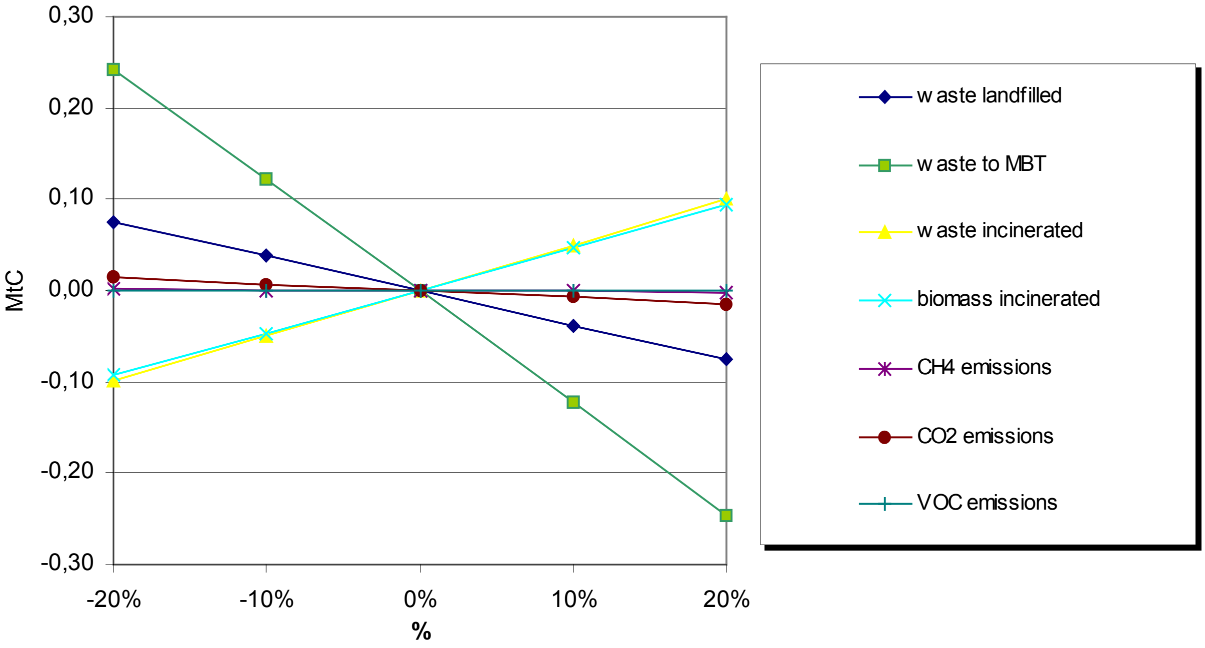
A 6-3.4 Sensitivities and Uncertainties

A 6-3.4.1 Sensitivity Analysis

The sensitivity analysis for the {WASTE} Module was carried out for the most determining driving parameters. These were the driving parameters for the split between incineration and MBT and for the recycling potentials. The DPs for recycling were varied simultaneously. The DPs were changed by increasing and decreasing the annual values by 10 and 20 percent. The occurred differences for Scenario 2 (TS) in amounts of Carbon in MtC are shown in the following figures for the year 2010.

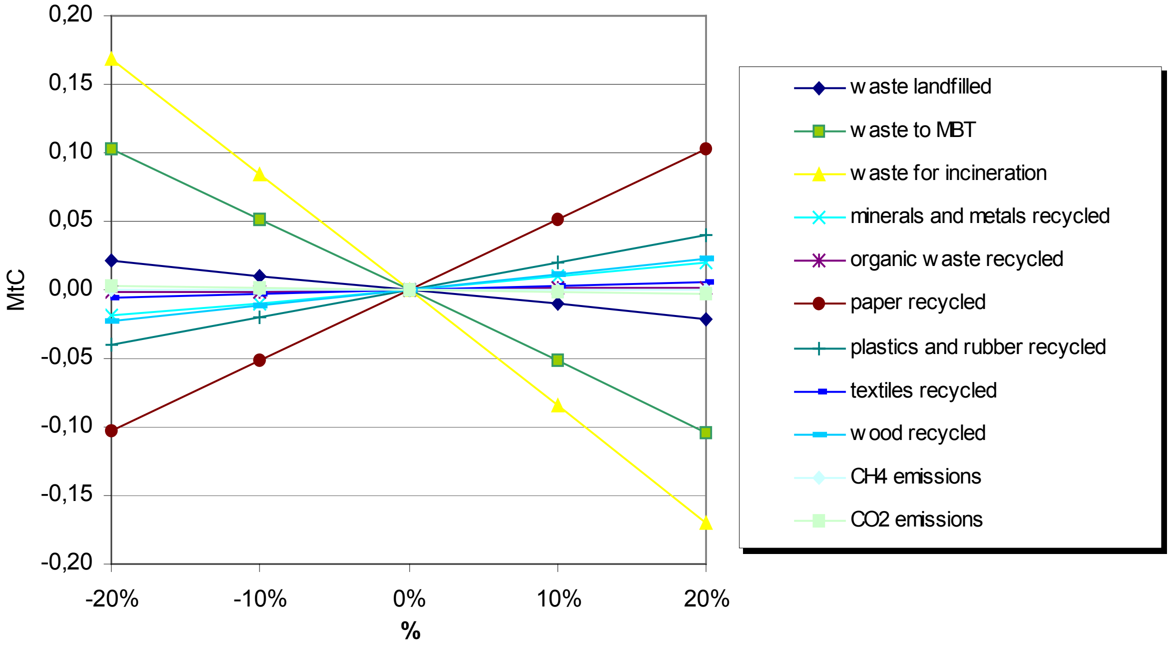
As energy supply (for waste treatment and transportation) is provided by the {ENERGY} module the emissions of combustion processes are counted in {ENERGY}. Due to this the sensitivity for all flows to atmosphere are generally not remarkable.

Figure A 6-7: Variation of split between incineration and MBT



The split between incineration and MBT (determined by DPP_% incineration and DPP_% mbt) was varied, the greatest differences resulted in the flows to MBT. The flow to incineration shows consequently a reverse behavior, but of minor magnitude, as a part of the MBT amounts are in any case passed to incineration. These amounts therefore increase with waste amounts to MBT. In context with increasing MBT amounts the landfill amounts and the CO_2 emissions rise. The CH_4 and VOC emissions are hardly affected as a high standard of emission reduction was assumed.

Figure A 6-8: Variation of Recycling potentials



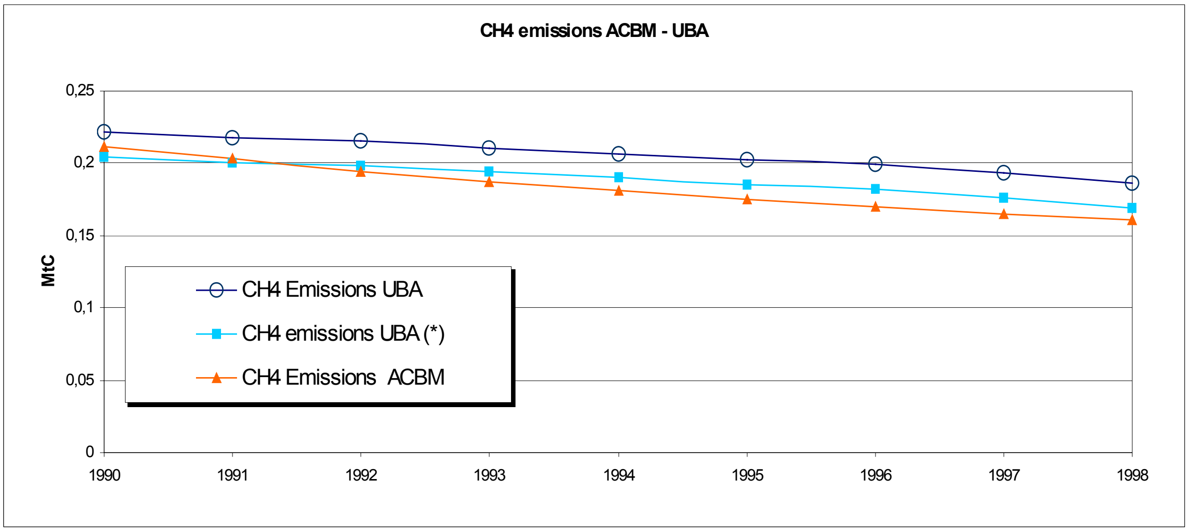
The variation of the driving parameters for the recycling potentials shows a direct effect on the recycled amounts and reverse effects on waste treatments. But none of the variations are strong enough to influence the simulation results of the whole model for the year 2010.

A 6-3.4.2 Uncertainties

As the waste flows from outside the module are the most determining flows, they cause the greatest uncertainties. Most of them have their origin in the consumption sub-process of the {PROD} module, where the inclusion of life time for groups of products and its functionality to represent a realistic link to the waste amounts has not established yet. Additionally the composition of each waste was difficult to obtain, in terms of materials for the mixed wastes as well as in term of organic compounds in each material. So many assumptions had to be made. There was also a general inconsistency in the definition of “waste” between a production point of view and a waste management point of view. A waste flow in industry could be handled as a waste final treatment, recycled internally, recycled in the same sector, or recycled in other sectors. Internal recycling, or recycling in the same industry sector was sometimes difficult to quantify.

As there were no data available for the initial content in the pool, so it was calculated to 12,5 MtC at 1990 from the average of the landfilled waste since 1970 (Steinlechner et al, 1994), reduced by the emissions since then. The emissions of landfill were calculated from the landfilled waste since 1970 by using the model of Tabasaran/Rettenberger from the estimated amounts of organic carbon. This was done to have a functional consistency between results of 1990-1998 and the scenarios. As can be seen in Figure A 6-9 the calculations are in the same range as the emissions of CH_4 published by “Umweltbundesamt” (Ritter 1999).

Figure A 6-9: Comparison of CH_4 emissions between UBA and ACBM



A 6-4 Discussion and Conclusions

A 6-4.1 Discussion

The landfill regulation had the most significant influence on the situation in the module {WASTE}. In both scenarios we got generally the same behavior, despite an increase in the waste amounts a decrease in the emissions occurred. But the assumed differences in the extent of the realization between the two scenarios led to different temporal behavior and velocity in the developments of the results. The influence of the partition of waste treatment technologies was not investigated. However from the results of the {WASTE} module alone no preference for one waste treatment technology could be derived, as the implied emissions partly arise in other modules. This is notably the {ENERGY} module, to which the waste for incineration, also that from the splitting process in MBT, was transferred. Moreover increased recycling resulted in reductions of raw material provision in the {PROD} module.

Due to the massive reduction of landfilling of materials with gas-building potential the CO_2 and CH_4 emissions from landfills showed a substantial decrease. It represented the most important emission reduction in the {WASTE} module and happened in a forced form in the sustainability scenario.

A 6-4.2 Applicability of results

The landfill regulation had the most significant influence on the situation in the module {WASTE}. Due to the massive reduction of landfilling of materials with gas-building potential the CO_2 and CH_4 emissions from landfills showed a substantial decrease. It represented the most important emission reduction in the {WASTE} module. Its magnitude increased proportionally to the extent to which the regulation was assumed to be realized in practice. As the {WASTE} module comprised only a part of the total waste treatment chain (incineration is dealt with in {ENERGY}) no conclusion for climate relevance or preference for one or the other treatment technology could be derived from the {WASTE} results alone. Maybe this can become a challenging task for the full carbon accounting model ACBM in the future.

A 6-4.3 Priorities for future work

The present model bases for the future waste development on relations between product consumption and waste amounts derived from the previous years, which were assumed to remain rather constant (except maxima in the consumption pool). As the product mix and the lifetime of products change with consumption behavior, some failure may appear the more the situation deviate from today. This could be amended by increasing the functionality in the link between the {WASTE} and the {PROD} module and inclusion of lifetime assumptions for groups of products for estimations of the waste amounts in the {PROD} module.

The composition of each waste is difficult to obtain in terms of materials for the mixed wastes as well as in term of organic compounds in each material. Many assumptions could be avoided with information about the waste system in terms of types of wastes and types of materials. This would also contribute to a better understanding of how changes in system components affect the overall system.

Finally the energy demand for the treatment processes regarded in the {WASTE} module and especially the implied transport expenditures need more detailed investigation especially as the situation in waste sector is in transition now.

A 6-5 References

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Annex 7

ACBM Model Description

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Hannes Schwaiger (2)
Ulrich Jäkel (2)
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Table of Contents

Annex 7 Description of the ACBM_Model

The model consist of **five** Excel files for the Simulation:

ACBM_MODEL.xls

MODUL_AGRO.xls

MODUL_ENERGY.xls

MODUL_FOREST.xls

MODUL_WASTE_PROD.xls,

and **two** Excel files to save the results of the simulation of the different scenarios:

NMC_Results.xls (the **N**o **M**ajor **C**hange scenario)

TS_Results.xls (the **T**owards **S**ustainability scenario),

and the meta database where the model parameters are documented:

ACBM_Meta database.xls

A 7-1. Install the Model

To Run the Model you have at first to copy ALL above listed files from the CD to the same directory at your Computer.

Remark: There is always a default version of the ACBM model on the CD and changes you made and which have destroyed the proper simulation, can be undone by copy and paste the default version from the CD again.

A 7-2. How to OPEN the Model

For the simulation ALL five Simulation files (see above) have to be opened. To do this it is necessary first to start Excel and then open the Files because due to this procedure the path of Excel is turned to the directory were the files have been stored. When you are ask if you want to activate the macros you have to answer with YES.

If the opening is not done in the right order problems when you want to save the scenario results would occur.

A 7-3. The contents of the Modules

A 7-3.1 ACBM_MODEL.xls

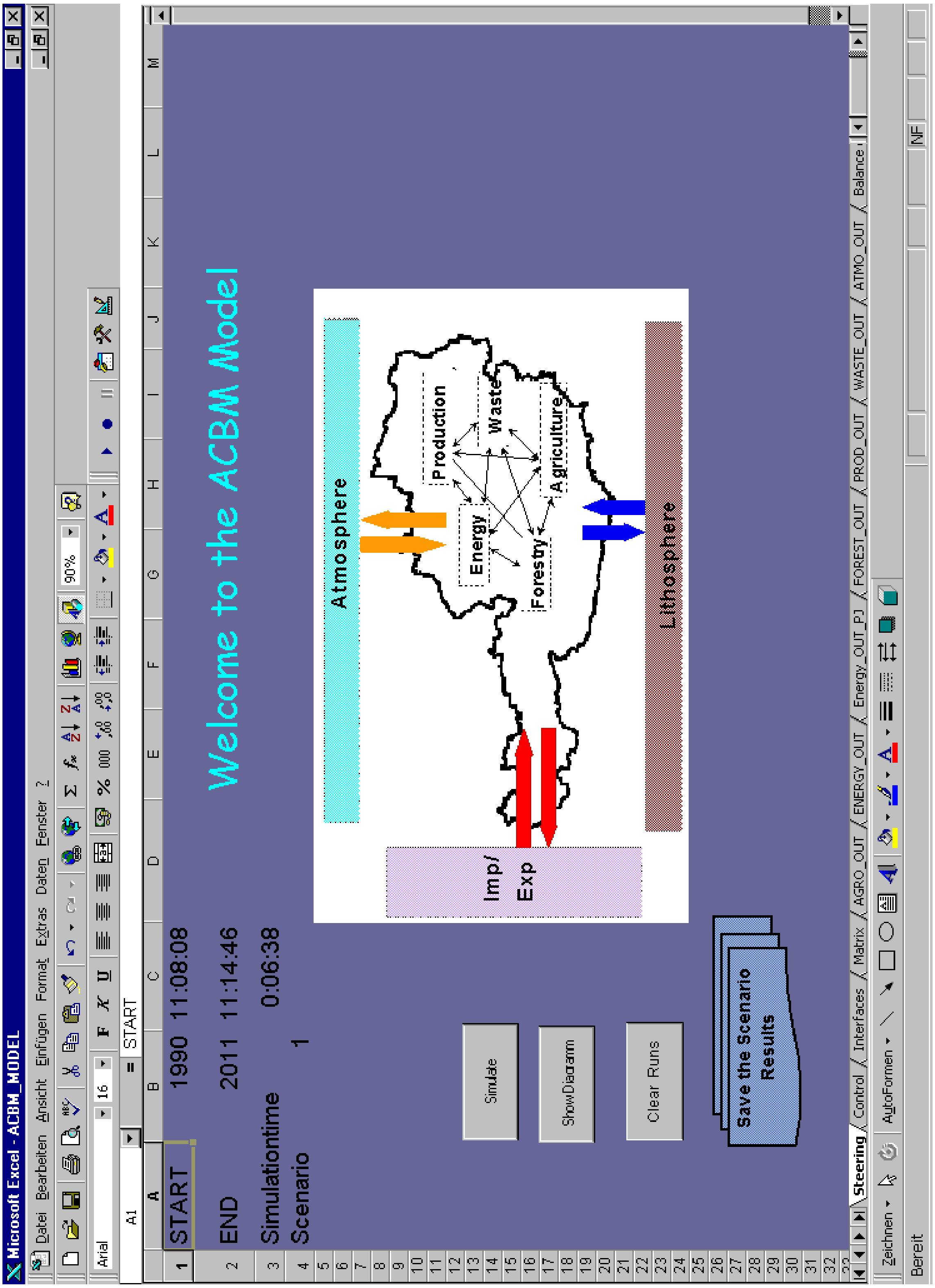
This is the steering file from where you can start the simulation, save the results and consider the most important outputs of the ACBM. The following Tables are in this file:

Sheet name	Short description
Steering	As shown in Figure A 7-1, in this sheet you can find the Buttons to **SIMULATE**, to **SHOW DIAGRAM** (only important ones) to **CLEAR RUNS** and to **Save the Scenario Results.**

	If you put the **Show Scenario Diagram** Button then an Window appears in which you can choose between different diagrams. To come back to the Steering Excel file (ACBM_MODEL.xls) you have go back with the pull down menu of Excel (named Window). The Button **clear runs** deletes all simulation results. It is necessary to click the Button if you change the End year of the simulation otherwise there could be a mixture of the results from different runs. In the Top left corner of the sheet the Starting year and End year of the simulation can be seen (Cells B1 and B2). All other modules are linked to this cells to ensure that all modules start and finish in the same year, thus changes of the End year should only be made there. Note: That in the recent version it is only possible to change the End year between 1991 and 2011. For a longer run to the future the parameters are not defined. Very important is the cell B4 where you can choose which scenario you want to simulate! Value 1 means NMC Scenario and Value 2 means TS Scenario! In the cells C1 C2 and C3 you can see the Start time the End time and the duration of the Simulation (Simulation time) on your Computer!
Control	This sheet was made to control the “faults” within the module. The values are derived as balance in the appropriate modules where the pool change within one year was compared with the change due to the inflows and outflows in the module. The “faults” were small compared to the total amount of the flows only about 0.08 %. The reason for the “faults” can be found in the problem of the time delay within one year. For more details see ACBM Final Report chapter 3.1.
Interfaces	Here are ALL interfaces between the modules listed. Figure A 7-2 shows a part of this list. The columns contents are described with comments as can be seen in the figure for the column A (Module). In this sheet you can find a table for the flows from ant to the Atmosphere within the Cells F164 to AE179. See Figure A 7-2a. This sheet also contains “IPCC-Mask” within the Cells D182 to AE218, where the IPCC relevant results are summarized. See Figure A 7-2b

MATRIX	In this sheet matrixes for the years 1990 t0 2010 are listed. Within this Matrixes all flows from one module to the other and from the other to the module can be seen.
AGRO_OUT, ENERGY_OUT, FOREST_OUT,PROD_OUT and WASTE_OUT	This tables show diagrams from flows of the appropriate Module, as can be seen in the name of the table, to ALL other modules over the simulation time. The unit of the flows is MtC/yr. In every sheet you can find a Button called ZOOM. This Button enables you to zoom into the diagrams by changing the maximum value of the Y-axe.
ENERGY_OUT_PJ	This shows the diagram of the flows from Energy to ALL other modules but in this case the unit is PJ/yr.
Balance of ATMO	This sheet shows the diagram of the total flows from and to ATMO as can be seen in the sheet Interfaces.
IPCC Flows	This sheet shows the diagram of the IPCC flows as listed in the sheet Interfaces.
DF_DP_List	Here are all Driving Parameters listed together.

Figure A 7-1: Screenshot of the ACBM_Model sheet Steering



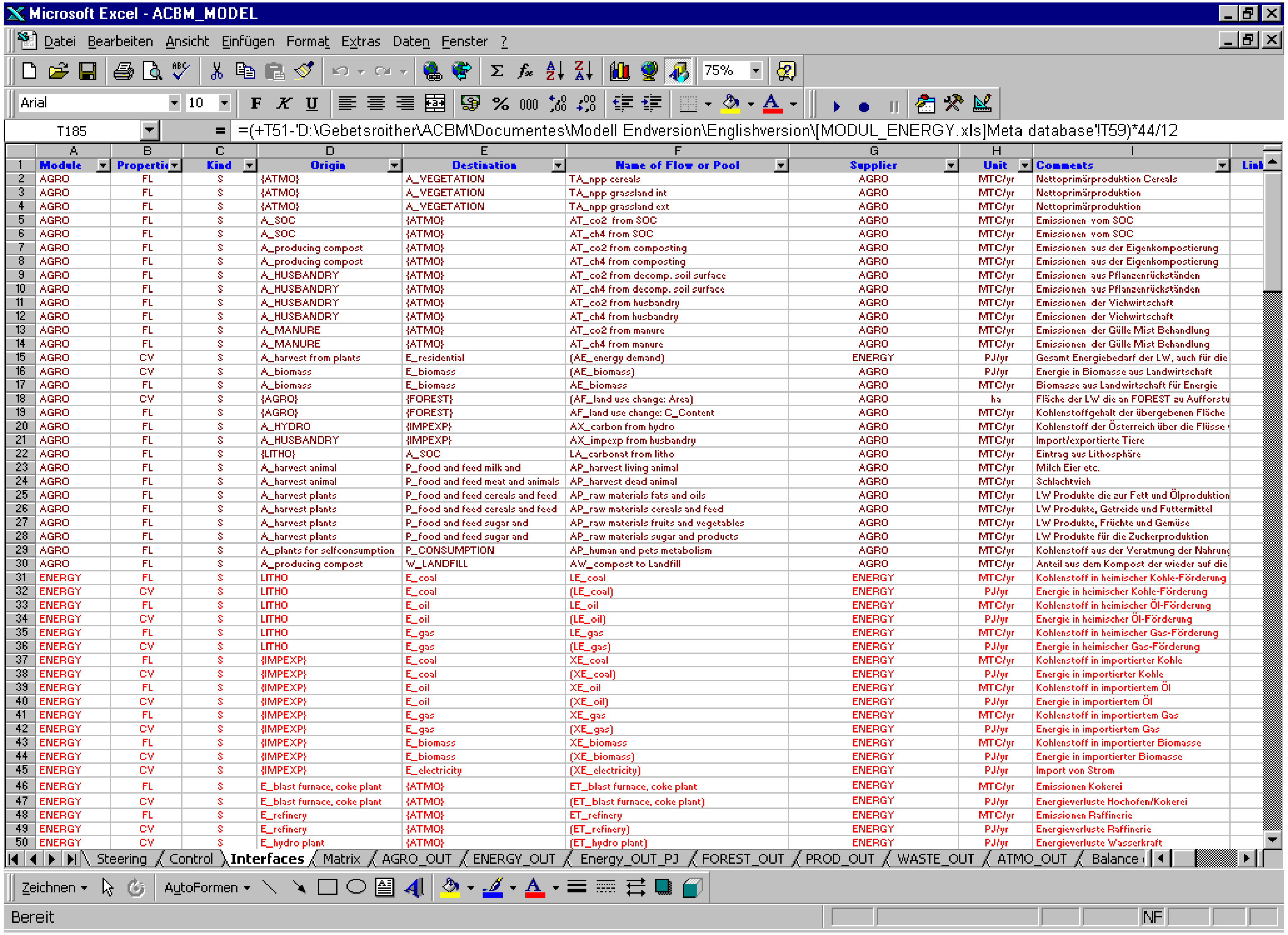
A1 = START

START	1990	11:08:08
END	2011	11:14:46
Simulationtime		0:06:38
Scenario	1	

Welcome to the ACBM Model

]

Figure A 7-2: Screenshot of the interface list



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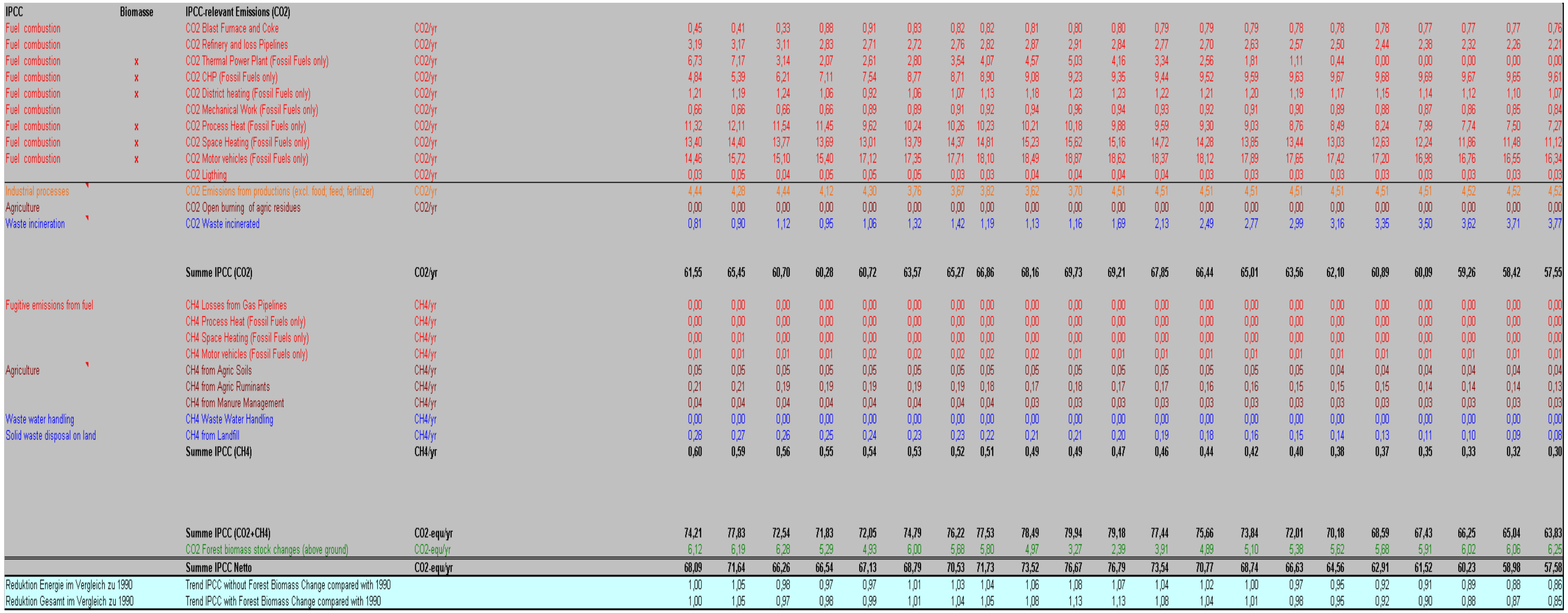
	A	B	C	D	E	F	G	H	I	
1	**Module**	**Properti**	**Kind**	**Origin**	**Destination**	**Name of Flow or Pool**	**Supplier**	**Unit**	**Comments**	**Lin**
2	AGRO	FL	S	{ATMO}	A_VEGETATION	TA_npp cereals	AGRO	MTC/yr	Nettoprimärproduktion Cereals	
3	AGRO	FL	S	{ATMO}	A_VEGETATION	TA_npp grassland int	AGRO	MTC/yr	Nettoprimärproduktion	
4	AGRO	FL	S	{ATMO}	A_VEGETATION	TA_npp grassland ext	AGRO	MTC/yr	Nettoprimärproduktion	
5	AGRO	FL	S	A_SOC	{ATMO}	AT_co2 from SOC	AGRO	MTC/yr	Emissionen vom SOC	
6	AGRO	FL	S	A_SOC	{ATMO}	AT_ch4 from SOC	AGRO	MTC/yr	Emissionen vom SOC	
7	AGRO	FL	S	A_producing compost	{ATMO}	AT_co2 from composting	AGRO	MTC/yr	Emissionen aus der Eigenkompostierung	
8	AGRO	FL	S	A_producing compost	{ATMO}	AT_ch4 from composting	AGRO	MTC/yr	Emissionen aus der Eigenkompostierung	
9	AGRO	FL	S	A_HUSBANDRY	{ATMO}	AT_co2 from decomp. soil surface	AGRO	MTC/yr	Emissionen aus Pflanzenrückständen	
10	AGRO	FL	S	A_HUSBANDRY	{ATMO}	AT_ch4 from decomp. soil surface	AGRO	MTC/yr	Emissionen aus Pflanzenrückständen	
11	AGRO	FL	S	A_HUSBANDRY	{ATMO}	AT_co2 from husbandry	AGRO	MTC/yr	Emissionen der Viehwirtschaft	
12	AGRO	FL	S	A_HUSBANDRY	{ATMO}	AT_ch4 from husbandry	AGRO	MTC/yr	Emissionen der Viehwirtschaft	
13	AGRO	FL	S	A_MANURE	{ATMO}	AT_co2 from manure	AGRO	MTC/yr	Emissionen der Gülle Mist Behandlung	
14	AGRO	FL	S	A_MANURE	{ATMO}	AT_ch4 from manure	AGRO	MTC/yr	Emissionen der Gülle Mist Behandlung	
15	AGRO	CV	S	A_harvest from plants	E_residential	(AE_energy demand)	ENERGY	PJ/yr	Gesamt Energiebedarf der LW, auch für die	
16	AGRO	CV	S	A_biomass	E_biomass	(AE_biomass)	AGRO	PJ/yr	Energie in Biomasse aus Landwirtschaft	
17	AGRO	FL	S	A_biomass	E_biomass	AE_biomass	AGRO	MTC/yr	Biomasse aus Landwirtschaft für Energie	
18	AGRO	CV	S	{AGRO}	{FOREST}	(AF_land use change: Area)	AGRO	ha	Fläche der LW die an FOREST zu Aufforstu	
19	AGRO	FL	S	{AGRO}	{FOREST}	AF_land use change: C_Content	AGRO	MTC/yr	Kohlenstoffgehalt der übergebenen Fläche	
20	AGRO	FL	S	A_HYDRO	{IMPEXP}	AX_carbon from hydro	AGRO	MTC/yr	Kohlenstoff der Österreich über die Flüsse	
21	AGRO	FL	S	A_HUSBANDRY	{IMPEXP}	AX_impexp from husbandry	AGRO	MTC/yr	Import/exportierte Tiere	
22	AGRO	FL	S	{LITHO}	A_SOC	LA_carbonat from litho	AGRO	MTC/yr	Eintrag aus Lithosphäre	
23	AGRO	FL	S	A_harvest animal	P_food and feed milk and	AP_harvest living animal	AGRO	MTC/yr	Milch Eier etc.	
24	AGRO	FL	S	A_harvest animal	P_food and feed meat and animals	AP_harvest dead animal	AGRO	MTC/yr	Schlachtvieh	
25	AGRO	FL	S	A_harvest plants	P_food and feed cereals and feed	AP_raw materials fats and oils	AGRO	MTC/yr	LW Produkte die zur Fett und Ölproduktion	
26	AGRO	FL	S	A_harvest plants	P_food and feed cereals and feed	AP_raw materials cereals and feed	AGRO	MTC/yr	LW Produkte, Getreide und Futtermittel	
27	AGRO	FL	S	A_harvest plants	P_food and feed sugar and	AP_raw materials fruits and vegetables	AGRO	MTC/yr	LW Produkte, Früchte und Gemüse	
28	AGRO	FL	S	A_harvest plants	P_food and feed sugar and	AP_raw materials sugar and products	AGRO	MTC/yr	LW Produkte für die Zuckerproduktion	
29	AGRO	FL	S	A_plants for selfconsumption	P_CONSUMPTION	AP_human and pets metabolism	AGRO	MTC/yr	Kohlenstoff aus der Veratmung der Nahrung	
30	AGRO	FL	S	A_producing compost	W_LANDFILL	AW_compost to Landfill	AGRO	MTC/yr	Anteil aus dem Kompost der wieder auf die	
31	ENERGY	FL	S	LITHO	E_coal	LE_coal	ENERGY	MTC/yr	Kohlenstoff in heimischer Kohle-Förderung	
32	ENERGY	CV	S	LITHO	E_coal	(LE_coal)	ENERGY	PJ/yr	Energie in heimischer Kohle-Förderung	
33	ENERGY	FL	S	LITHO	E_oil	LE_oil	ENERGY	MTC/yr	Kohlenstoff in heimischer Öl-Förderung	
34	ENERGY	CV	S	LITHO	E_oil	(LE_oil)	ENERGY	PJ/yr	Energie in heimischer Öl-Förderung	
35	ENERGY	FL	S	LITHO	E_gas	LE_gas	ENERGY	MTC/yr	Kohlenstoff in heimischer Gas-Förderung	
36	ENERGY	CV	S	LITHO	E_gas	(LE_gas)	ENERGY	PJ/yr	Energie in heimischer Gas-Förderung	
37	ENERGY	FL	S	{IMPEXP}	E_coal	XE_coal	ENERGY	MTC/yr	Kohlenstoff in importierter Kohle	
38	ENERGY	CV	S	{IMPEXP}	E_coal	(XE_coal)	ENERGY	PJ/yr	Energie in importierter Kohle	
39	ENERGY	FL	S	{IMPEXP}	E_oil	XE_oil	ENERGY	MTC/yr	Kohlenstoff in importiertem Öl	
40	ENERGY	CV	S	{IMPEXP}	E_oil	(XE_oil)	ENERGY	PJ/yr	Energie in importiertem Öl	
41	ENERGY	FL	S	{IMPEXP}	E_gas	XE_gas	ENERGY	MTC/yr	Kohlenstoff in importiertem Gas	
42	ENERGY	CV	S	{IMPEXP}	E_gas	(XE_gas)	ENERGY	PJ/yr	Energie in importiertem Gas	
43	ENERGY	FL	S	{IMPEXP}	E_biomass	XE_biomass	ENERGY	MTC/yr	Kohlenstoff in importierter Biomasse	
44	ENERGY	CV	S	{IMPEXP}	E_biomass	(XE_biomass)	ENERGY	PJ/yr	Energie in importierter Biomasse	
45	ENERGY	CV	S	{IMPEXP}	E_electricity	(XE_electricity)	ENERGY	PJ/yr	Import von Strom	
46	ENERGY	FL	S	E_blast furnace, coke plant	{ATMO}	ET_blast furnace, coke plant	ENERGY	MTC/yr	Emissionen Kokerei	
47	ENERGY	CV	S	E_blast furnace, coke plant	{ATMO}	(ET_blast furnace, coke plant)	ENERGY	PJ/yr	Energieverluste Hochofen/Kokerei	
48	ENERGY	FL	S	E_refinery	{ATMO}	ET_refinery	ENERGY	MTC/yr	Emissionen Raffinerie	
49	ENERGY	CV	S	E_refinery	{ATMO}	(ET_refinery)	ENERGY	PJ/yr	Energieverluste Raffinerie	
50	ENERGY	CV	S	E_hydro plant	{ATMO}	(ET_hydro plant)	ENERGY	PJ/yr	Energieverluste Wasserkraft	

Figure A 7-2a: Summarized Results of the Flows from and to the Atmosphere.

All Flows from and to the Atmosphere summarized																						
Total Flow to ATMO	MTC/yr	43,92	45,02	42,98	42,92	42,99	43,73	44,01	44,75	45,24	45,81	45,42	44,94	44,47	43,99	43,51	43,04	42,62	42,35	42,07	41,79	41,52
Total Flows from ATMO	MTC/yr	29,49	29,49	28,73	29,15	29,42	29,32	28,94	29,37	29,52	29,52	29,47	29,43	29,39	29,36	29,32	29,29	29,26	29,22	29,18	29,14	29,10
Net Flow to ATMO	**MTC/yr**	**14,43**	**15,53**	**14,24**	**13,77**	**13,57**	**14,41**	**15,06**	**15,38**	**15,72**	**16,30**	**15,94**	**15,51**	**15,08**	**14,63**	**14,19**	**13,75**	**13,37**	**13,12**	**12,88**	**12,65**	**12,42**
CO2-C Flow to ATMO	MTC/yr	43,44	44,56	42,54	42,49	42,56	43,31	43,60	44,36	44,85	45,43	45,05	44,58	44,13	43,66	43,20	42,74	42,34	42,07	41,80	41,54	41,28
CO2-C Flows from ATMO	MTC/yr	-29,49	-29,49	-28,73	-29,15	-29,42	-29,32	-28,94	-29,37	-29,52	-29,52	-29,47	-29,43	-29,39	-29,36	-29,32	-29,29	-29,26	-29,22	-29,18	-29,14	-29,10
CO2-C Net Flow to ATMO	**MTC/yr**	**13,95**	**15,07**	**13,80**	**13,34**	**13,15**	**13,99**	**14,65**	**14,98**	**15,33**	**15,92**	**15,57**	**15,16**	**14,74**	**14,31**	**13,87**	**13,45**	**13,08**	**12,85**	**12,62**	**12,39**	**12,18**
CO2 Net Flow to ATMO	**CO2/yr**	**51,15**	**55,25**	**50,61**	**48,93**	**48,21**	**51,30**	**53,73**	**54,94**	**56,22**	**58,36**	**57,11**	**55,58**	**54,05**	**52,45**	**50,86**	**49,30**	**47,95**	**47,10**	**46,27**	**45,44**	**44,65**
C-CH4 Flows to ATMO	MTC/yr	0,46	0,45	0,43	0,42	0,41	0,41	0,40	0,39	0,37	0,37	0,36	0,35	0,34	0,32	0,31	0,30	0,28	0,27	0,26	0,25	0,24
C-CH4 Flows from ATMO	MTC/yr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C-CH4 Net Flow to ATMO	**MTC/yr**	**0,46**	**0,45**	**0,43**	**0,42**	**0,41**	**0,41**	**0,40**	**0,39**	**0,37**	**0,37**	**0,36**	**0,35**	**0,34**	**0,32**	**0,31**	**0,30**	**0,28**	**0,27**	**0,26**	**0,25**	**0,24**
CH4 Net Flow to ATMO	**CH4/yr**	**0,62**	**0,60**	**0,57**	**0,56**	**0,55**	**0,54**	**0,53**	**0,52**	**0,50**	**0,49**	**0,48**	**0,46**	**0,45**	**0,43**	**0,41**	**0,39**	**0,38**	**0,36**	**0,34**	**0,33**	**0,31**
Other C-Flows to ATMO	MTC/yr	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,00	0,00	0,00
CO2 equivalents to ATMO	**CO2-eq / yr**	**64,12**	**67,80**	**62,62**	**60,64**	**59,71**	**62,68**	**64,85**	**65,80**	**66,68**	**68,70**	**67,21**	**65,33**	**63,44**	**61,47**	**59,50**	**57,58**	**55,88**	**54,68**	**53,52**	**52,36**	**51,24**
CO2 equivalents to ATMO compared with the year 1990		1	1,06	0,98	0,95	0,93	0,98	1,01	1,03	1,04	1,07	1,05	1,02	0,99	0,96	0,93	0,90	0,87	0,85	0,83	0,82	0,79915

Figure A 7-2b: The IPCC Mask as part if the interface sheet



IPCC	Biomasse	IPCC-relevant Emissions (CO2)																						
Fuel combustion		CO2 Blast Furnace and Coke	CO2/yr	0,45	0,41	0,33	0,88	0,91	0,83	0,82	0,82	0,81	0,80	0,80	0,79	0,79	0,79	0,78	0,78	0,78	0,77	0,77	0,77	0,76
Fuel combustion		CO2 Refinery and loss Pipelines	CO2/yr	3,19	3,17	3,11	2,83	2,71	2,72	2,76	2,82	2,87	2,91	2,84	2,77	2,70	2,63	2,57	2,50	2,44	2,38	2,32	2,26	2,21
Fuel combustion	x	CO2 Thermal Power Plant (Fossil Fuels only)	CO2/yr	6,73	7,17	3,14	2,07	2,61	2,80	3,54	4,07	4,57	5,03	4,16	3,34	2,56	1,81	1,11	0,44	0,00	0,00	0,00	0,00	0,00
Fuel combustion	x	CO2 CHP (Fossil Fuels only)	CO2/yr	4,84	5,39	6,21	7,11	7,54	8,77	8,71	8,90	9,08	9,23	9,35	9,44	9,52	9,59	9,63	9,67	9,68	9,69	9,67	9,65	9,61
Fuel combustion	x	CO2 District heating (Fossil Fuels only)	CO2/yr	1,21	1,19	1,24	1,06	0,92	1,06	1,07	1,13	1,18	1,23	1,23	1,22	1,21	1,20	1,19	1,17	1,15	1,14	1,12	1,10	1,07
Fuel combustion		CO2 Mechanical Work (Fossil Fuels only)	CO2/yr	0,66	0,66	0,66	0,66	0,89	0,89	0,91	0,92	0,94	0,96	0,94	0,93	0,92	0,91	0,90	0,89	0,88	0,87	0,86	0,85	0,84
Fuel combustion	x	CO2 Process Heat (Fossil Fuels only)	CO2/yr	11,32	12,11	11,54	11,45	9,62	10,24	10,26	10,23	10,21	10,18	9,88	9,59	9,30	9,03	8,76	8,49	8,24	7,99	7,74	7,50	7,27
Fuel combustion	x	CO2 Space Heating (Fossil Fuels only)	CO2/yr	13,40	14,40	13,77	13,69	13,01	13,79	14,37	14,81	15,23	15,62	15,16	14,72	14,28	13,85	13,44	13,03	12,63	12,24	11,86	11,48	11,12
Fuel combustion	x	CO2 Motor vehicles (Fossil Fuels only)	CO2/yr	14,46	15,72	15,10	15,40	17,12	17,35	17,71	18,10	18,49	18,87	18,62	18,37	18,12	17,89	17,65	17,42	17,20	16,98	16,76	16,55	16,34
		CO2 Ligthing	CO2/yr	0,03	0,05	0,04	0,05	0,05	0,05	0,03	0,03	0,04	0,04	0,04	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
Industrial processes		CO2 Emissions from productions (excl. food; feed; fertilizer)	CO2/yr	4,44	4,28	4,44	4,12	4,30	3,76	3,67	3,82	3,62	3,70	4,51	4,51	4,51	4,51	4,51	4,51	4,51	4,51	4,52	4,52	4,52
Agriculture		CO2 Open burning of agric residues	CO2/yr	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Waste incineration		CO2 Waste incinerated		0,81	0,90	1,12	0,95	1,06	1,32	1,42	1,19	1,13	1,16	1,69	2,13	2,49	2,77	2,99	3,16	3,35	3,50	3,62	3,71	3,77
		Summe IPCC (CO2)	**CO2/yr**	**61,55**	**65,45**	**60,70**	**60,28**	**60,72**	**63,57**	**65,27**	**66,86**	**68,16**	**69,73**	**69,21**	**67,85**	**66,44**	**65,01**	**63,56**	**62,10**	**60,89**	**60,09**	**59,26**	**58,42**	**57,55**
Fugitive emissions from fuel		CH4 Losses from Gas Pipelines	CH4/yr	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
		CH4 Process Heat (Fossil Fuels only)	CH4/yr	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
		CH4 Space Heating (Fossil Fuels only)	CH4/yr	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
		CH4 Motor vehicles (Fossil Fuels only)	CH4/yr	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,02	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Agriculture		CH4 from Agric Soils	CH4/yr	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,04	0,04	0,04	0,04	0,04	0,04
		CH4 from Agric Ruminants	CH4/yr	0,21	0,21	0,19	0,19	0,19	0,19	0,19	0,18	0,17	0,18	0,17	0,17	0,16	0,16	0,15	0,15	0,15	0,14	0,14	0,14	0,13
		CH4 from Manure Management	CH4/yr	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
Waste water handling		CH4 Waste Water Handling	CH4/yr	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Solid waste disposal on land		CH4 from Landfill	CH4/yr	0,28	0,27	0,26	0,25	0,24	0,23	0,23	0,22	0,21	0,21	0,20	0,19	0,18	0,16	0,15	0,14	0,13	0,11	0,10	0,09	0,08
		Summe IPCC (CH4)	**CH4/yr**	**0,60**	**0,59**	**0,56**	**0,55**	**0,54**	**0,53**	**0,52**	**0,51**	**0,49**	**0,49**	**0,47**	**0,46**	**0,44**	**0,42**	**0,40**	**0,38**	**0,37**	**0,35**	**0,33**	**0,32**	**0,30**
		Summe IPCC (CO2+CH4)	**CO2-equ/yr**	**74,21**	**77,83**	**72,54**	**71,83**	**72,05**	**74,79**	**76,22**	**77,53**	**78,49**	**79,94**	**79,18**	**77,44**	**75,66**	**73,84**	**72,01**	**70,18**	**68,59**	**67,43**	**66,25**	**65,04**	**63,83**
		CO2 Forest biomass stock changes (above ground)	CO2-equ/yr	6,12	6,19	6,28	5,29	4,93	6,00	5,68	5,80	4,97	3,27	2,39	3,91	4,89	5,10	5,38	5,62	5,68	5,91	6,02	6,06	6,25
		Summe IPCC Netto	**CO2-equ/yr**	**68,09**	**71,64**	**66,26**	**66,54**	**67,13**	**68,79**	**70,53**	**71,73**	**73,52**	**76,67**	**76,79**	**73,54**	**70,77**	**68,74**	**66,63**	**64,56**	**62,91**	**61,52**	**60,23**	**58,98**	**57,58**
Reduktion Energie im Vergleich zu 1990		Trend IPCC without Forest Biomass Change compared with 1990		1,00	1,05	0,98	0,97	0,97	1,01	1,03	1,04	1,06	1,08	1,07	1,04	1,02	1,00	0,97	0,95	0,92	0,91	0,89	0,88	0,86
Reduktion Gesamt im Vergleich zu 1990		Trend IPCC with Forest Biomass Change compared with 1990		1,00	1,05	0,97	0,98	0,99	1,01	1,04	1,05	1,08	1,13	1,13	1,08	1,04	1,01	0,98	0,95	0,92	0,90	0,88	0,87	0,85

A 7-3.2 Further details to the sheet Interfaces and DF_DP_List (driving force driving parameter list)

Interfaces:

The sheet Interfaces (interface list) contains following columns: These columns and abbreviations are useful to identify every parameter quickly and to aggregate e.g. all control variables from all modules.

Module: Shows to which module the parameter belongs.

Properties: The Properties of the parameters are labelled with abbreviation. Due to this with the filter modus the same compartments (e.g. pools) of all modules can be selected.

FL:= Flow

CV:=Control variable (steering parameter)

Kind: The parameter is labelled if it is an interface Flow (S) or it is an internal Flow (I).

Origin : Determines from where the parameter "starts"

Destination: Determines where the parameter “ends”

Name of Flow or Pool: The names of the parameters are listed according to the use nomenclature

Supplier: Here is listed who has the responsibility for the value. This means e.g. that an flow which belongs to AGRO (column A) and is here listed with ENERGY is an so called pulled parameter as the value of it is delivered be ENERGY

Unit: Shows the Unit of the parameter.

Comments: This column gives further details to the parameters. (in German)

Link to or from Module: Shows the connected module.

1990 to 2020: Shows the year to which the value belongs.

DF_DP_List:

This list shows the 210 driving parameter an their appropriate driving force as well as driving bag.

If the Button  is clicked the DF_DP_List would be actualized, so that the values for the chosen scenario are copied to this sheet.

The sheet contains following columns:

Module: Shows to which module the parameter belongs.

Driving Bag: Number of driving forces are bundled in a Driving Bag.

Driving Force: The Driving Forces are the main elements of the scenario projections.

Driving Parameter: Driving Forces were translated into 210 operational Driving Parameters which are actual numbers with proper dimensions that can parameterize the model equations

Driving Parameter Unit per year: Shows the unit of the driving parameter

Primary Effect on: Shows the parameter to which the DP has its first effect

Secondary Effect on: Shows the parameter to which the DP has its second effect

1990 to 2020: Shows the year to which the value of the DP belongs.

A 7-3.3 AGRO.xls:

The steering sheet of the AGRO module is labelled Steering. From there it is possible to run the module in a standalone modus by a click on the start Button.

The following table gives a short description of the sheets in the module. For more details are in the module Excel comments involved.

Sheet name	Short description
Steering	This sheet is the steering sheet an there you can start the simulation as standalone version. You should be carefully if you change the parameters in this sheet because then you could destroy the connection to the ACBM_Model.xls file. So if you want to change the scenario it would be better if you would change this in the ACBM_Model.xls file.
DP_LISTE_NMC, DP_LISTE_TS	This two sheets contains the tables for the driving parameter of the two scenarios and diagrams of the changes of these parameters from 1990 to 2010.
INPUT_OUPUT	This sheets shows all interfaces from or to AGRO .
DIA_HUS	This sheets shows diagrams which demonstrates the behavior of the HUSBANDRY. Buttons on the right sight of the diagrams enables to ZOOM into the diagram by changing the scale of the Y-axe.
Meta database	This sheet shows all flows pools processes and inputs of the other modules which are used in AGRO. In this sheet there are also a few control parameters and the calculation of the pool and flow changes at the bottom of the table listed.
Soil data farmland	This sheet shows the parameters for the calculation of the soil carbon on cereal, fruit and crop land.
DIA_soil farmland	This sheets shows the diagram of the soil carbon on cereal, fruits and cropland.
Soil data grassland int	This sheet shows the parameters for the calculation of the soil carbon on grassland intensive cultivated
DIA_soil grassland int	This sheets shows the diagram of the soil carbon on grassland intensive cultivated.
Soil data grassland ext	This sheet shows the parameters for the calculation of the soil carbon on grassland extensive cultivated
DIA_soil grassland ext	This sheets shows the diagram of the soil carbon on grassland extensive cultivated.
Parameter_Soiltyps	In this sheet the main parameter for the calculation of the soil model are listed.

A 7-3.4 MODUL_ENERGY.xls:

The main sheet of the module is called Steering, from where you can run the module as standalone module!

The file “MODUL_ENERGY.xls” consists of the following 6 sheets with diagrams and 11 sheets with tables.

Sheet name	Short description
Diagram	
Diag_Sectors	The energy demand of the three sectors industry, transportation and residential is shown
Diag_KindOfUsefulEnergy	The different kinds of useful energy are shown
Diag_FinalEnergyCarrier	The different final energy carrier are shown
Diag_EnergyTransformation	The energy flows through the transformation plants
Diag_Fuel	The different fuels are shown
Diag_Emissions	The different carbon flows to the atmosphere are shown
Sheets	
TabDiag	Sheet with the values for the diagrams
Control	Sheet for controlling the in- and outputs of energy and carbon for the different elements of {ENERGY}
Steering	Sheet with the Buttons to run the energy module
Carbon flows	Sheet with the different carbon flows of the module
Energy flows	Sheet with the different energy flows of the module
Industry	Sheet with energy flows of the sector „industry“ (from useful energy to final energy carrier)
Transportation	Sheet with energy flows of the sector „transportation“ (from useful energy to final energy carrier)
Residential	Sheet with the energy flows of the sector „residential“ (from useful energy to final energy carrier)
Residential	Sheet with the energy flows of the sector „residential“ (from useful energy to final energy carrier)
DF_DP_List1	Sheet with the driving parameter for scenario 1 (NMC).
DF_DP_List2	Sheet with the driving parameter for scenario 2 (TS).
INPUT_OUTPUT	Sheet with the carbon and control flows with the other modules.
Meta database	Sheet with all carbon and control flows of {ENERGY}.

Buttons	
Start of energy module	The Button to start the calculation of {ENERGY} as “stand-alone calculation” (without interactions with other modules).
Clear the energy module:	This Button clears the results, that were calculated in „start of energy module“.
Controls	The Button can be used to control if the sum of the matching driving parameters are one. If not a message box appears and the matching parameter would be marked.
Diagrams	The Button to create the diagrams.
Clear diagrams	The Button to clear the diagrams.

A 7-3.5 MODUL_FOREST.xls

The module {FOREST} is implemented into VBA macros using MS BASIC language. Spreadsheet cells are used only for reading input and writing model output, there are no calculations performed within spreadsheet cells.

The {FOREST} module is organized into the following Excel sheets, used for different purpose:

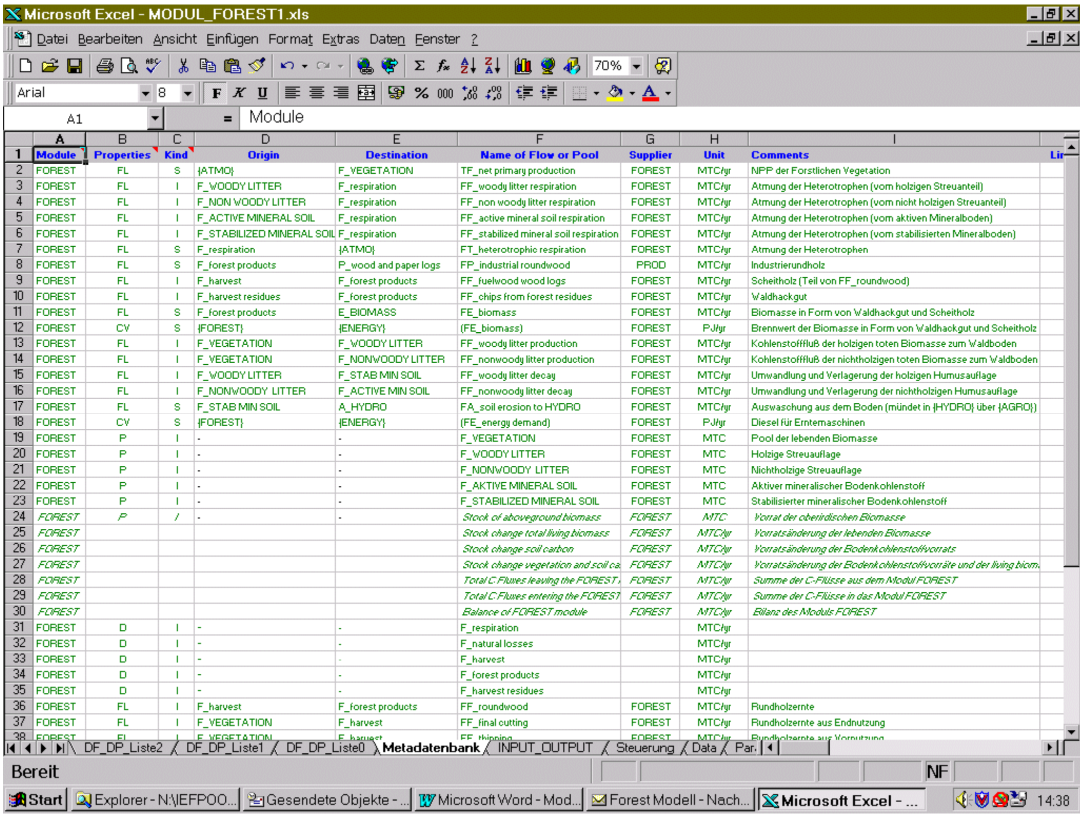
- INPUT_OUTPUT
- Meta database
- DF_DP lists (DP_DF_List0, 1, 2)
- Steering
- Parameters
- Data
- Large Matrix

Sheet name	Short description
INPUT_OUTPUT	As in all ACBM modules, the “INPUT_OUTPUT” sheet serves as the linkage to the other ACBM modules; demand of roundwood and fuelwood is read as well as the annually afforested land which is passed from {AGRO} module. These values are read before the calculation of an annual {FOREST} module step, afterwards the resulting outputs as relevant for other modules are written to this sheet as well. Note that the demand of energy in PJ/year (row 13) is provided by the model in the next year (row 5).
Meta database	In this sheet all C-flows from and to the {FOREST} module, as well as control variables, dispatchers and pools are provided for the modeling period 1990–2010. In addition, some important pools and flows for the interpretation of the entire ACBM output are provided in rows 24-30.

DF_DP_List1	The sheet includes all necessary driving parameters used within the scenario NMC, following the defined appropriate driving bags and driving forces. The parameters are read for each time step.
DF_DP_List2	The sheet includes all necessary driving parameters used within the scenario TS, following the defined appropriate driving bags and driving forces.
DF_DP_List0 (hidden sheet)	The sheet includes all driving parameters used within both scenarios, but set constant. Therefore the DF_DP_List0 sheet is a dummy scenario, only for internal use which does not set any trends but keeps driving parameters on their 1990 values. These data are not used within the ACBM simulations.
Steering	The sheet „Steering“ contains the simulation relevant initial information: how many tree species included, the number of age classes used within the module run, the starting year and the number of time steps to perform. Here can you find the Button to SIMULATE and all intern parameters for the model run (see report A4 Annex). In cell B3 it can be decided which initial areas of species specific age class distribution (AFI 86/90 = 1988; AFI92/96 = 1994) is chosen. Cells B1 and B2 describes the chosen number of tree species and age classes (see also data sheet). Note that for the age classes IX-XII the area is summarized within age class VIII. Additionally internal parameters to be used in the run are stored in this sheet as well. They can be changed using a graphical user interface accessible via the starting Button (SIMULATION). These menu parameters can be brought back to their default values by using a reset routine, the program then copies a parameter set stored in the sheet “Parameters” to the “Steering” sheet.
Data	The sheet includes tables of the initial database for the forest modeling. It contains the standard input of the model like initial area distribution referring to the defined age classes, initial standing stock and soil carbon. Furthermore expansion factors, increments, thinning rates and calamities are also defined here. All data within this sheet are organized within age classes of 20 years width as they could be entered manually from the forest inventory
Parameter	The sheet “Parameter” contains the backup of the sheet “Steering” and is only used for resetting tree species specific parameters to their default values.
Large Matrix (hidden sheet)	As the “Data” sheet serves as the storage of initial values there is a related sheet called “Large Matrix”, where values from “Data” are copied after interpolation into classes of one year width. In contrast to the “Data” sheet, “Large Matrix” is read and also data are written to it during the model run. Every

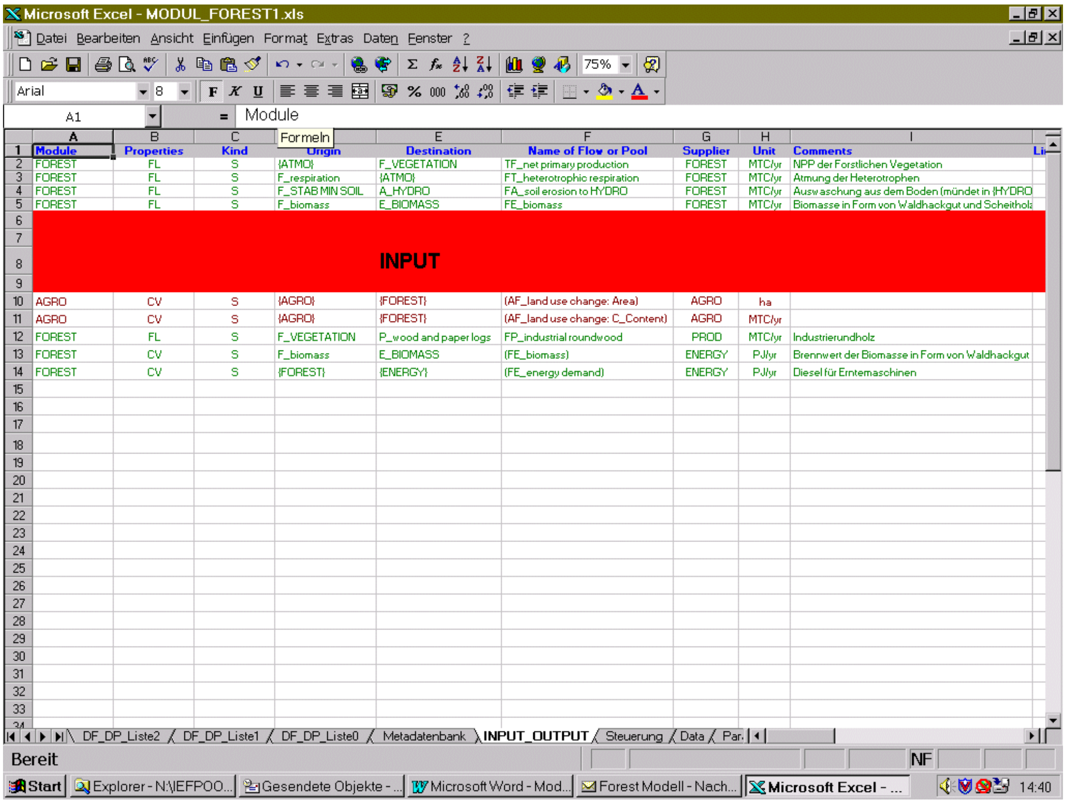
	model time step, stores new systems state variables within this sheet. Therefore the sheet "Large Matrix" needs an initialization at model simulation beginning in order to confirm the correct initial state.

Figure A 7-3: Screenshot of the Model table "Meta database"



	A	B	C	D	E	F	G	H	I
1	Module	Properties	Kind	Origin	Destination	Name of Flow or Pool	Supplier	Unit	Comments
2	FOREST	FL	S	{ATMO}	F_VEGETATION	TF_net primary production	FOREST	MTC/yr	NPP der Forstlichen Vegetation
3	FOREST	FL	I	F_WOODY LITTER	F_respiration	FF_woody litter respiration	FOREST	MTC/yr	Atmung der Heterotrophen (vom holzigen Streuanteil)
4	FOREST	FL	I	F_NON WOODY LITTER	F_respiration	FF_non woody litter respiration	FOREST	MTC/yr	Atmung der Heterotrophen (vom nicht holzigen Streuanteil)
5	FOREST	FL	I	F_ACTIVE MINERAL SOIL	F_respiration	FF_active mineral soil respiration	FOREST	MTC/yr	Atmung der Heterotrophen (vom aktiven Mineralboden)
6	FOREST	FL	I	F_STABILIZED MINERAL SOIL	F_respiration	FF_stabilized mineral soil respiration	FOREST	MTC/yr	Atmung der Heterotrophen (vom stabilisierten Mineralboden)
7	FOREST	FL	S	F_respiration	{ATMO}	FT_heterotrophic respiration	FOREST	MTC/yr	Atmung der Heterotrophen
8	FOREST	FL	S	F_forest products	P_wood and paper logs	FP_industrial roundwood	PROD	MTC/yr	Industrierundholz
9	FOREST	FL	I	F_harvest	F_forest products	FF_fuelwood wood logs	FOREST	MTC/yr	Scheitholz (Teil von FF_roundwood)
10	FOREST	FL	I	F_harvest residues	F_forest products	FF_chips from forest residues	FOREST	MTC/yr	Waldhackgut
11	FOREST	FL	S	F_forest products	E_BIOMASS	FE_biomass	FOREST	MTC/yr	Biomasse in Form von Waldhackgut und Scheitholz
12	FOREST	CV	S	{FOREST}	{ENERGY}	(FE_biomass)	FOREST	PJ/yr	Brennwert der Biomasse in Form von Waldhackgut und Scheitholz
13	FOREST	FL	I	F_VEGETATION	F_WOODY LITTER	FF_woody litter production	FOREST	MTC/yr	Kohlenstofffluß der holzigen toten Biomasse zum Waldboden
14	FOREST	FL	I	F_VEGETATION	F_NONWOODY LITTER	FF_nonwoody litter production	FOREST	MTC/yr	Kohlenstofffluß der nichtholzigen toten Biomasse zum Waldboden
15	FOREST	FL	I	F_WOODY LITTER	F_STAB MIN SOIL	FF_woody litter decay	FOREST	MTC/yr	Umwandlung und Verlagerung der holzigen Humusauflage
16	FOREST	FL	I	F_NONWOODY LITTER	F_ACTIVE MIN SOIL	FF_nonwoody litter decay	FOREST	MTC/yr	Umwandlung und Verlagerung der nichtholzigen Humusauflage
17	FOREST	FL	S	F_STAB MIN SOIL	A_HYDRO	FA_soil erosion to HYDRO	FOREST	MTC/yr	Auswaschung aus dem Boden (mündet in {HYDRO} über {AGRO})
18	FOREST	CV	S	{FOREST}	{ENERGY}	(FE_energy demand)	FOREST	PJ/yr	Diesel für Erntemaschinen
19	FOREST	P	I	-	-	F_VEGETATION	FOREST	MTC	Pool der lebenden Biomasse
20	FOREST	P	I	-	-	F_WOODY LITTER	FOREST	MTC	Holzige Streuauflage
21	FOREST	P	I	-	-	F_NONWOODY LITTER	FOREST	MTC	Nichtholzige Streuauflage
22	FOREST	P	I	-	-	F_AKTIVE MINERAL SOIL	FOREST	MTC	Aktiver mineralischer Bodenkohlenstoff
23	FOREST	P	I	-	-	F_STABILIZED MINERAL SOIL	FOREST	MTC	Stabilisierter mineralischer Bodenkohlenstoff
24	*FOREST*	*P*	*I*	-	-	*Stock of aboveground biomass*	*FOREST*	*MTC*	*Vorrat der oberirdischen Biomasse*
25	*FOREST*					*Stock change total living biomass*	*FOREST*	*MTC/yr*	*Vorratsänderung der lebenden Biomasse*
26	*FOREST*					*Stock change soil carbon*	*FOREST*	*MTC/yr*	*Vorratsänderung der Bodenkohlenstoffvorrats*
27	*FOREST*					*Stock change vegetation and soil ca*	*FOREST*	*MTC/yr*	*Vorratsänderung der Bodenkohlenstoffvorräte und der living biom*
28	*FOREST*					*Total C Fluxes leaving the FOREST*	*FOREST*	*MTC/yr*	*Summe der C-Flüsse aus dem Modul FOREST*
29	*FOREST*					*Total C Fluxes entering the FOREST*	*FOREST*	*MTC/yr*	*Summe der C-Flüsse in das Modul FOREST*
30	*FOREST*					*Balance of FOREST module*	*FOREST*	*MTC/yr*	*Bilanz des Moduls FOREST*
31	FOREST	D	I	-	-	F_respiration		MTC/yr	
32	FOREST	D	I	-	-	F_natural losses		MTC/yr	
33	FOREST	D	I	-	-	F_harvest		MTC/yr	
34	FOREST	D	I	-	-	F_forest products		MTC/yr	
35	FOREST	D	I	-	-	F_harvest residues		MTC/yr	
36	FOREST	FL	I	F_harvest	F_forest products	FF_roundwood	FOREST	MTC/yr	Rundholzernte
37	FOREST	FL	I	F_VEGETATION	F_harvest	FF_final cutting	FOREST	MTC/yr	Rundholzernte aus Endnutzung
38	FOREST	FL	I	F_VEGETATION	F_harvest	FF_thinning	FOREST	MTC/yr	Rundholzernte aus Vornutzung

Figure A 7-4: Screenshot of the sheet “INPUT/OUTPUT”



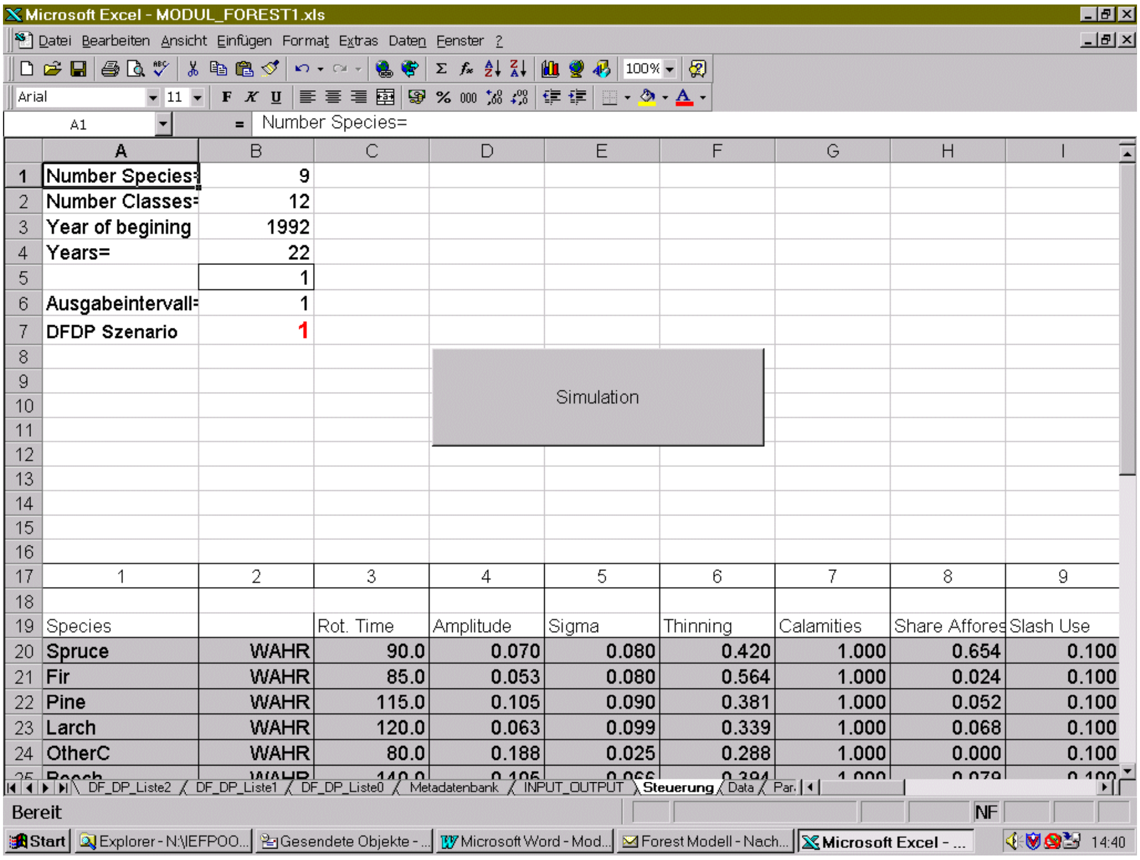
= Module

Module	Properties	Kind	Origin	Destination	Name of Flow or Pool	Supplier	Unit	Comments
FOREST	FL	S	{ATMO}	F_VEGETATION	TF_net primary production	FOREST	MTC/yr	NPP der Forstlichen Vegetation
FOREST	FL	S	F_respiration	{ATMO}	FT_heterotrophic respiration	FOREST	MTC/yr	Atmung der Heterotrophen
FOREST	FL	S	F_STAB MIN SOIL	A_HYDRO	FA_soil erosion to HYDRO	FOREST	MTC/yr	Auswaschung aus dem Boden (mündet in {HYDRO
FOREST	FL	S	F_biomass	E_BIOMASS	FE_biomass	FOREST	MTC/yr	Biomasse in Form von Waldhackgut und Scheitholz

INPUT

AGRO	CV	S	{AGRO}	{FOREST}	(AF_land use change: Area)	AGRO	ha	
AGRO	CV	S	{AGRO}	{FOREST}	(AF_land use change: C_Content)	AGRO	MTC/yr	
FOREST	FL	S	F_VEGETATION	P_wood and paper logs	FP_industrial roundwood	PROD	MTC/yr	Industrierundholz
FOREST	CV	S	F_biomass	E_BIOMASS	(FE_biomass)	ENERGY	PJ/yr	Brennwert der Biomasse in Form von Waldhackgut
FOREST	CV	S	{FOREST}	{ENERGY}	(FE_energy demand)	ENERGY	PJ/yr	Diesel für Erntemaschinen

Figure A 7-5: Screenshot of the sheet “Steering”



= Number Species=

Number Species=	9
Number Classes=	12
Year of begining	1992
Years=	22
	1
Ausgabeintervall=	1
DFDP Szenario	1

1	2	3	4	5	6	7	8	9
Species		Rot. Time	Amplitude	Sigma	Thinning	Calamities	Share Affores	Slash Use
Spruce	WAHR	90.0	0.070	0.080	0.420	1.000	0.654	0.100
Fir	WAHR	85.0	0.053	0.080	0.564	1.000	0.024	0.100
Pine	WAHR	115.0	0.105	0.090	0.381	1.000	0.052	0.100
Larch	WAHR	120.0	0.063	0.099	0.339	1.000	0.068	0.100
OtherC	WAHR	80.0	0.188	0.025	0.288	1.000	0.000	0.100

A 7-3.6 MODUL_WASTE_PROD.xls

This is the file for calculation and documentation for the modules PROD and WASTE. The file comprises the following Table:

Sheet name	Short description
Steering	Here can you find the Buttons to start the simulation for the PROD and the WASTE module in a standing alone modus (without changes in the other modules). You can input the years for start and finish and certify them by pressing **OK** both times. To start the simulation for the two modules you have to press **START WASTE and PROD** You can also find here the input tables for the values of the “driving parameters” for both scenarios.
INPUT_OUTPUT_PROD	Here are the interfaces for all inputs and outputs of the PROD module listed. The columns contents are described with comments.
INPUT_OUTPUT_WASTE	Here are the interfaces for all inputs and outputs of the WASTE module listed. The columns contents are described with comments.
Meta database PROD	This data sheet contains all flows, their values and additional information for all flows within the PROD module of the years 1990 – 2010.
Meta database WASTE	This data sheet contains all flows, their values and additional information for all flows within the WASTE module of the years 1990 – 2010.
DF_DP_List_NMC	This sheet contains all driving parameters and the driving forces and driving bags they depend on and their values for the years 1990 – 2010 for both modules for the scenario “no major change”.
DF_DP_List_TS	This sheet contains all driving parameters and the driving forces and driving bags they depend on and their values for the years 1990 – 2010 for both modules for the scenario “towards sustainability”.

A 7-3.7 NMC_Results.xls

This file saves the results of one simulation. Thus different scenarios can be compared if the one is **saved as** for example NMC_Results_1.xls and the second as NMC_Results_2.xls files. The default result file has to be NMC_Result.xls and should not be changed otherwise the Button ‘Save the Simulation Results’ can’t be used further more.

The file contents following sheets:

Sheet name	Short description
Control	This sheet was made to control the “faults” in within the module. The values are derived as balance in the appropriate modules where the pool change within one year was compared with the change due to the inflows and outflows in the module. The “faults” are were small compared to the total amount of the flows only 0.08 %. The reason for this can be found in the problem of the time delay within one year. For more details see ACBM Final Report chapter 3.1.
Interfaces	Here are ALL interfaces between the modules listed. Figure A 7-2 a part of this list. The columns contents are described with comments as can be seen in the figure for the column A (Module). For a detailed description of the columns see chapter A 7.3.2
Matrix	In this sheet matrixes for the years 1990 t0 2010 are listed. Within this Matrixes all flows from one module to the other and from the other to the module for every year can be seen.
Agro, Energy, Forest, Prod, Waste	This sheets contain the meta-database of the modules. Every flow, pool, control variable etc. are listed with their appropriate values for the yeas 1990 to 2010.
Diagram	This sheet shows the change of the net flow from ATMO, the change of the IPPC flow without and the change of the IPCC flow with the biomas compared to the year 1990.
Enddiagramm	This sheet shows the figure where the “IPCC- Results” and the Full carbon Accounting- Results” (ACBM-Results) can be seen
EndTab	In this sheet the data for the figures Enddiagramm and Enddiagramm Uncertainty are listed.
Enddiagramm Uncertainty	This sheet shows the figure of the result under consideration of its uncertainty.

A 7-3.8 TS_Results.xls

Has the same content as the NMC_Results.xls file, but with the exception that the Results for the Towards Sustainability scenario are shown!!!

A 7-3.9 ACBM_Meta database.xls

This file contains the three sheets the meta database itself the sheet called Interfaces (interface list) and the sheet DF_DP_List. This files contains no data.

Within the sheets the following can be found.

Sheet name	Short description
Meta database	This sheet contains the main element of the model as flows, pools, control variables, dispatchers, processes. For explanation see the chapter of the definition of the used parameters. (A 1: Nomenclature)
Interfaces	Here are ALL interfaces between the modules are listed The list is an part of the meta database. Figure A 7-2 shows a part of this list. The columns contents are described with comments as can be seen in the figure for the column A (Module). For a detailed description of the columns see chapter A 7.3.2
DF_DP_List	List of all DP used in the ACBM model.

Meta database:

The sheet contains following columns: These columns and abbreviations are useful to identify every parameter quickly and to aggregate e.g. all control variables from all modules.

Module: Shows to which module the parameter belongs.

Properties: The Properties of the parameters are labelled with abbreviation. Due to this with the filter modus the same compartments (e.g. pools) of all modules can be selected.

FL:= Flow

P:= Pool

D:= Dispatcher

PR:= Process

M:= Modul

CV:=Control variable (steering parameter)

Kind: The parameter is labelled if it is an interface Flow (S) or it is an internal Flow (I).

Origin : Determines from where the parameter "starts"

Destination: Determines where the parameter “ends”

Name of Flow or Pool: The names of the parameters are listed according to the use nomenclature

Supplier: Here is listed who has the responsibility for the value. This means e.g. that an flow which belongs to AGRO (column A) and is here listed with ENERGY is an so called pulled parameter as the value of it is delivered be ENERGY

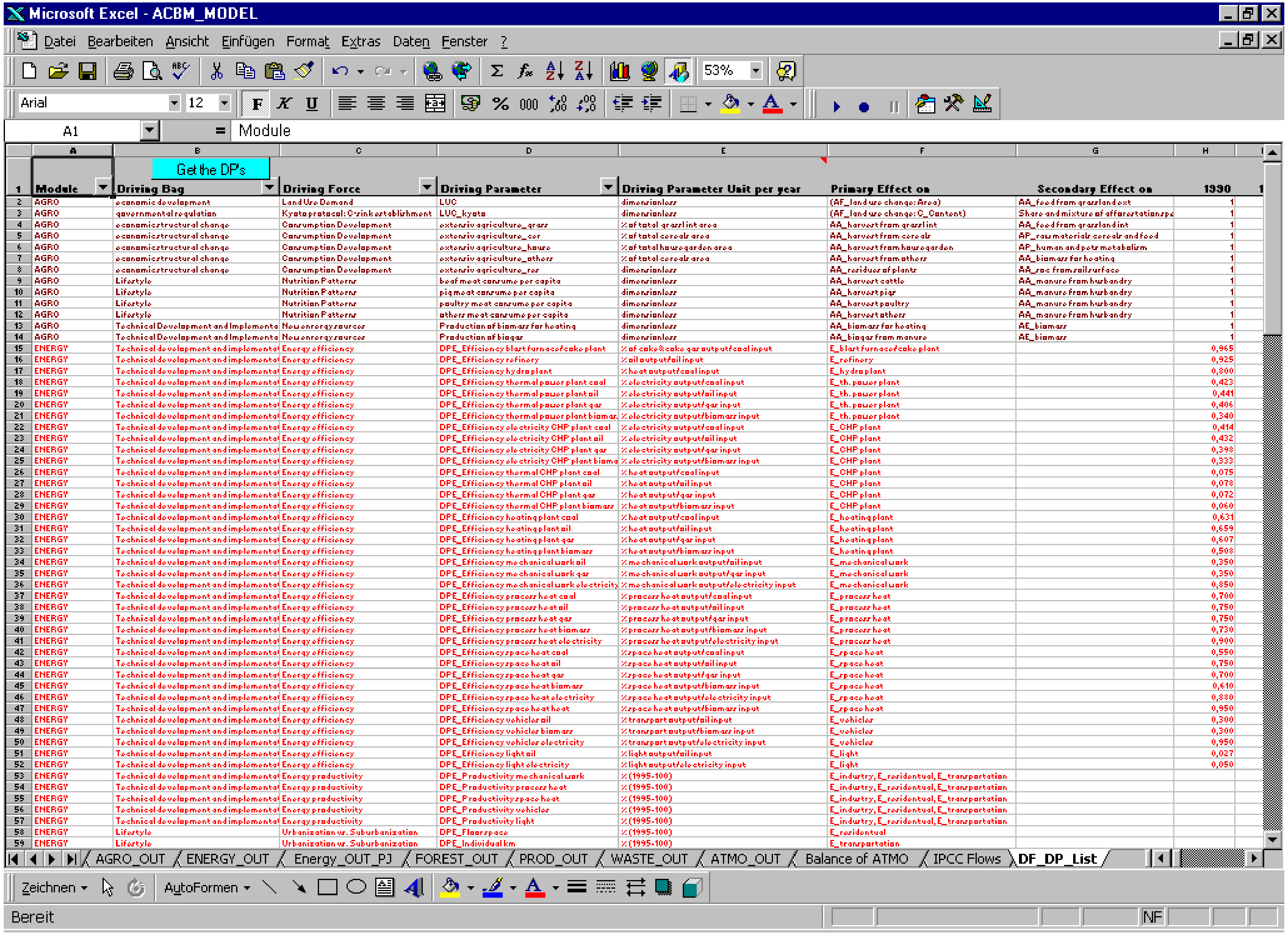
Unit: Shows the Unit of the parameter.

Comments: This column gives further details to the parameters. (in German)

Link to or from Module: Shows the connected module.

1990 to 2020: Shows the year to which the value belong

Figure A 7-6: Screenshot of the Df_DP_List

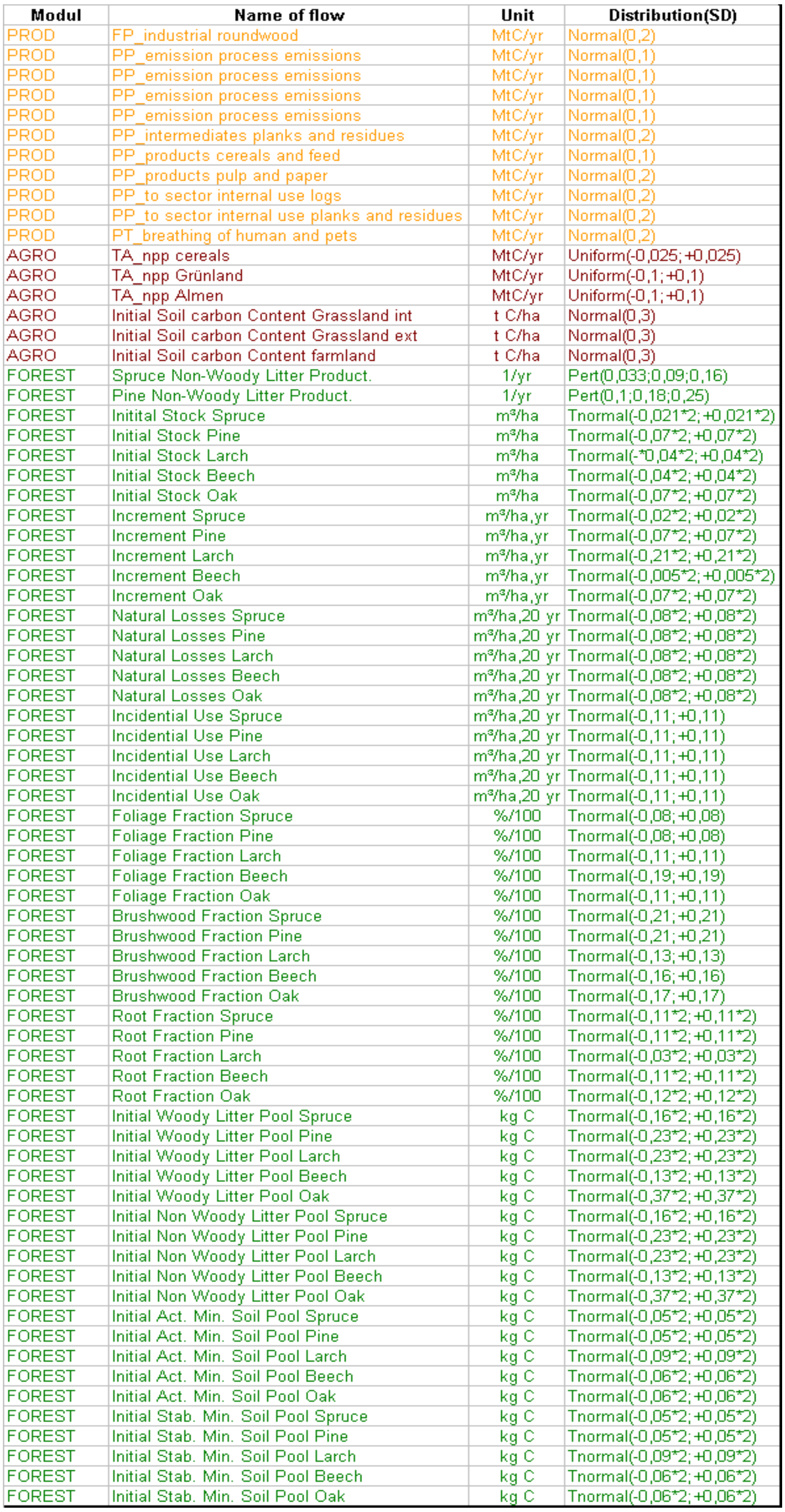


1	Module	Driving Bag	Driving Force	Driving Parameter	Driving Parameter Unit per year	Primary Effect on	Secondary Effect on	1990
2	AGRO	economic development	Land Use Demand	LUC	dimensionless	(AF_land use change: Area)	AA_food from grassland ext	1
3	AGRO	governmental regulation	Kyoto protocol: C-sink establishment	LUC_kyoto	dimensionless	(AF_land use change: C_Content)	Share and mixture of afforestation spe	1
4	AGRO	economic structural change	Consumption Development	extensiv agriculture_grass	% of total grasslint area	AA_harvest from grasslint	AA_food from grassland int	1
5	AGRO	economic structural change	Consumption Development	extensiv agriculture_cer	% of total cereals area	AA_harvest from cereals	AP_raw materials cereals and food	1
6	AGRO	economic structural change	Consumption Development	extensiv agriculture_house	% of total housegarden area	AA_harvest from housegarden	AP_human and pets metabolism	1
7	AGRO	economic structural change	Consumption Development	extensiv agriculture_others	% of total cereals area	AA_harvest from others	AA_biomass for heating	1
8	AGRO	economic structural change	Consumption Development	extensiv agriculture_res	dimensionless	AA_residues of plants	AA_soc from soil surface	1
9	AGRO	Lifestyle	Nutrition Patterns	beef meat consume per capita	dimensionless	AA_harvest cattle	AA_manure from husbandry	1
10	AGRO	Lifestyle	Nutrition Patterns	pig meat consume per capita	dimensionless	AA_harvest pigs	AA_manure from husbandry	1
11	AGRO	Lifestyle	Nutrition Patterns	poultry meat consume per capita	dimensionless	AA_harvest poultry	AA_manure from husbandry	1
12	AGRO	Lifestyle	Nutrition Patterns	others meat consume per capita	dimensionless	AA_harvest others	AA_manure from husbandry	1
13	AGRO	Technical Development and Implementa	New energy sources	Production of biomass for heating	dimensionless	AA_biomass for heating	AE_biomass	1
14	AGRO	Technical Development and Implementa	New energy sources	Production of biogas	dimensionless	AA_biogas from manure	AE_biomass	1
15	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency blast furnace/coke plant	% of coke&coke gas output/coal input	E_blast furnace/coke plant		0,965
16	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency refinery	% oil output/oil input	E_refinery		0,925
17	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency hydro plant	% heat output/coal input	E_hydro plant		0,800
18	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency thermal power plant coal	% electricity output/coal input	E_th. power plant		0,423
19	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency thermal power plant oil	% electricity output/oil input	E_th. power plant		0,441
20	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency thermal power plant gas	% electricity output/gas input	E_th. power plant		0,406
21	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency thermal power plant biomas	% electricity output/biomass input	E_th. power plant		0,340
22	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency electricity CHP plant coal	% electricity output/coal input	E_CHP plant		0,414
23	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency electricity CHP plant oil	% electricity output/oil input	E_CHP plant		0,432
24	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency electricity CHP plant gas	% electricity output/gas input	E_CHP plant		0,398
25	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency electricity CHP plant bioma	% electricity output/biomass input	E_CHP plant		0,333
26	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency thermal CHP plant coal	% heat output/coal input	E_CHP plant		0,075
27	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency thermal CHP plant oil	% heat output/oil input	E_CHP plant		0,078
28	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency thermal CHP plant gas	% heat output/gas input	E_CHP plant		0,072
29	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency thermal CHP plant biomass	% heat output/biomass input	E_CHP plant		0,060
30	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency heating plant coal	% heat output/coal input	E_heating plant		0,631
31	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency heating plant oil	% heat output/oil input	E_heating plant		0,659
32	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency heating plant gas	% heat output/gas input	E_heating plant		0,607
33	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency heating plant biomass	% heat output/biomass input	E_heating plant		0,508
34	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency mechanical work oil	% mechanical work output/oil input	E_mechanical work		0,350
35	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency mechanical work gas	% mechanical work output/gas input	E_mechanical work		0,350
36	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency mechanical work electricity	% mechanical work output/electricity input	E_mechanical work		0,850
37	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency process heat coal	% process heat output/coal input	E_process heat		0,700
38	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency process heat oil	% process heat output/oil input	E_process heat		0,750
39	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency process heat gas	% process heat output/gas input	E_process heat		0,750
40	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency process heat biomass	% process heat output/biomass input	E_process heat		0,730
41	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency process heat electricity	% process heat output/electricity input	E_process heat		0,900
42	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency space heat coal	%space heat output/coal input	E_space heat		0,550
43	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency space heat oil	%space heat output/oil input	E_space heat		0,750
44	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency space heat gas	%space heat output/gas input	E_space heat		0,700
45	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency space heat biomass	%space heat output/biomass input	E_space heat		0,610
46	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency space heat electricity	%space heat output/electricity input	E_space heat		0,880
47	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency space heat heat	%space heat output/biomass input	E_space heat		0,950
48	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency vehicles oil	% transport output/oil input	E_vehicles		0,300
49	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency vehicles biomass	% transport output/biomass input	E_vehicles		0,300
50	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency vehicles electricity	% transport output/electricity input	E_vehicles		0,950
51	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency light oil	% light output/oil input	E_light		0,027
52	ENERGY	Technical development and implementat	Energy efficiency	DPE_Efficiency light electricity	% light output/electricity input	E_light		0,050
53	ENERGY	Technical development and implementat	Energy productivity	DPE_Productivity mechanical work	% (1995-100)	E_industry, E_residentual, E_transportation		
54	ENERGY	Technical development and implementat	Energy productivity	DPE_Productivity process heat	% (1995-100)	E_industry, E_residentual, E_transportation		
55	ENERGY	Technical development and implementat	Energy productivity	DPE_Productivity space heat	% (1995-100)	E_industry, E_residentual, E_transportation		
56	ENERGY	Technical development and implementat	Energy productivity	DPE_Productivity vehicles	% (1995-100)	E_industry, E_residentual, E_transportation		
57	ENERGY	Technical development and implementat	Energy productivity	DPE_Productivity light	% (1995-100)	E_industry, E_residentual, E_transportation		
58	ENERGY	Lifestyle	Urbanization vs. Suburbanization	DPE_Floorspace	% (1995-100)	E_residentual		
59	ENERGY	Lifestyle	Urbanization vs. Suburbanization	DPE_Individual km	% (1995-100)	E_transportation		

A 7-4 Used Inputdata for the uncertainty analysis

The Figure shows the Uncertainty functions and the used parameters.

Figure A 7-7: Inputdata for the Uncertainty analysis



Modul	Name of flow	Unit	Distribution(SD)
PROD	FP_industrial roundwood	MtC/yr	Normal(0,2)
PROD	PP_emission process emissions	MtC/yr	Normal(0,1)
PROD	PP_emission process emissions	MtC/yr	Normal(0,1)
PROD	PP_emission process emissions	MtC/yr	Normal(0,1)
PROD	PP_emission process emissions	MtC/yr	Normal(0,1)
PROD	PP_intermediates planks and residues	MtC/yr	Normal(0,2)
PROD	PP_products cereals and feed	MtC/yr	Normal(0,1)
PROD	PP_products pulp and paper	MtC/yr	Normal(0,2)
PROD	PP_to sector internal use logs	MtC/yr	Normal(0,2)
PROD	PP_to sector internal use planks and residues	MtC/yr	Normal(0,2)
PROD	PT_breathing of human and pets	MtC/yr	Normal(0,2)
AGRO	TA_npp cereals	MtC/yr	Uniform(-0,025;+0,025)
AGRO	TA_npp Grünland	MtC/yr	Uniform(-0,1;+0,1)
AGRO	TA_npp Almen	MtC/yr	Uniform(-0,1;+0,1)
AGRO	Initial Soil carbon Content Grassland int	t C/ha	Normal(0,3)
AGRO	Initial Soil carbon Content Grassland ext	t C/ha	Normal(0,3)
AGRO	Initial Soil carbon Content farmland	t C/ha	Normal(0,3)
FOREST	Spruce Non-Woody Litter Product.	1/yr	Pert(0,033;0,09;0,16)
FOREST	Pine Non-Woody Litter Product.	1/yr	Pert(0,1;0,18;0,25)
FOREST	Initital Stock Spruce	m^3/ha	Tnormal(-0,021*2;+0,021*2)
FOREST	Initial Stock Pine	m^3/ha	Tnormal(-0,07*2;+0,07*2)
FOREST	Initial Stock Larch	m^3/ha	Tnormal(-*0,04*2;+0,04*2)
FOREST	Initial Stock Beech	m^3/ha	Tnormal(-0,04*2;+0,04*2)
FOREST	Initial Stock Oak	m^3/ha	Tnormal(-0,07*2;+0,07*2)
FOREST	Increment Spruce	m^3/ha,yr	Tnormal(-0,02*2;+0,02*2)
FOREST	Increment Pine	m^3/ha,yr	Tnormal(-0,07*2;+0,07*2)
FOREST	Increment Larch	m^3/ha,yr	Tnormal(-0,21*2;+0,21*2)
FOREST	Increment Beech	m^3/ha,yr	Tnormal(-0,005*2;+0,005*2)
FOREST	Increment Oak	m^3/ha,yr	Tnormal(-0,07*2;+0,07*2)
FOREST	Natural Losses Spruce	m^3/ha,20 yr	Tnormal(-0,08*2;+0,08*2)
FOREST	Natural Losses Pine	m^3/ha,20 yr	Tnormal(-0,08*2;+0,08*2)
FOREST	Natural Losses Larch	m^3/ha,20 yr	Tnormal(-0,08*2;+0,08*2)
FOREST	Natural Losses Beech	m^3/ha,20 yr	Tnormal(-0,08*2;+0,08*2)
FOREST	Natural Losses Oak	m^3/ha,20 yr	Tnormal(-0,08*2;+0,08*2)
FOREST	Incidential Use Spruce	m^3/ha,20 yr	Tnormal(-0,11;+0,11)
FOREST	Incidential Use Pine	m^3/ha,20 yr	Tnormal(-0,11;+0,11)
FOREST	Incidential Use Larch	m^3/ha,20 yr	Tnormal(-0,11;+0,11)
FOREST	Incidential Use Beech	m^3/ha,20 yr	Tnormal(-0,11;+0,11)
FOREST	Incidential Use Oak	m^3/ha,20 yr	Tnormal(-0,11;+0,11)
FOREST	Foliage Fraction Spruce	%/100	Tnormal(-0,08;+0,08)
FOREST	Foliage Fraction Pine	%/100	Tnormal(-0,08;+0,08)
FOREST	Foliage Fraction Larch	%/100	Tnormal(-0,11;+0,11)
FOREST	Foliage Fraction Beech	%/100	Tnormal(-0,19;+0,19)
FOREST	Foliage Fraction Oak	%/100	Tnormal(-0,11;+0,11)
FOREST	Brushwood Fraction Spruce	%/100	Tnormal(-0,21;+0,21)
FOREST	Brushwood Fraction Pine	%/100	Tnormal(-0,21;+0,21)
FOREST	Brushwood Fraction Larch	%/100	Tnormal(-0,13;+0,13)
FOREST	Brushwood Fraction Beech	%/100	Tnormal(-0,16;+0,16)
FOREST	Brushwood Fraction Oak	%/100	Tnormal(-0,17;+0,17)
FOREST	Root Fraction Spruce	%/100	Tnormal(-0,11*2;+0,11*2)
FOREST	Root Fraction Pine	%/100	Tnormal(-0,11*2;+0,11*2)
FOREST	Root Fraction Larch	%/100	Tnormal(-0,03*2;+0,03*2)
FOREST	Root Fraction Beech	%/100	Tnormal(-0,11*2;+0,11*2)
FOREST	Root Fraction Oak	%/100	Tnormal(-0,12*2;+0,12*2)
FOREST	Initial Woody Litter Pool Spruce	kg C	Tnormal(-0,16*2;+0,16*2)
FOREST	Initial Woody Litter Pool Pine	kg C	Tnormal(-0,23*2;+0,23*2)
FOREST	Initial Woody Litter Pool Larch	kg C	Tnormal(-0,23*2;+0,23*2)
FOREST	Initial Woody Litter Pool Beech	kg C	Tnormal(-0,13*2;+0,13*2)
FOREST	Initial Woody Litter Pool Oak	kg C	Tnormal(-0,37*2;+0,37*2)
FOREST	Initial Non Woody Litter Pool Spruce	kg C	Tnormal(-0,16*2;+0,16*2)
FOREST	Initial Non Woody Litter Pool Pine	kg C	Tnormal(-0,23*2;+0,23*2)
FOREST	Initial Non Woody Litter Pool Larch	kg C	Tnormal(-0,23*2;+0,23*2)
FOREST	Initial Non Woody Litter Pool Beech	kg C	Tnormal(-0,13*2;+0,13*2)
FOREST	Initial Non Woody Litter Pool Oak	kg C	Tnormal(-0,37*2;+0,37*2)
FOREST	Initial Act. Min. Soil Pool Spruce	kg C	Tnormal(-0,05*2;+0,05*2)
FOREST	Initial Act. Min. Soil Pool Pine	kg C	Tnormal(-0,05*2;+0,05*2)
FOREST	Initial Act. Min. Soil Pool Larch	kg C	Tnormal(-0,09*2;+0,09*2)
FOREST	Initial Act. Min. Soil Pool Beech	kg C	Tnormal(-0,06*2;+0,06*2)
FOREST	Initial Act. Min. Soil Pool Oak	kg C	Tnormal(-0,06*2;+0,06*2)
FOREST	Initial Stab. Min. Soil Pool Spruce	kg C	Tnormal(-0,05*2;+0,05*2)
FOREST	Initial Stab. Min. Soil Pool Pine	kg C	Tnormal(-0,05*2;+0,05*2)
FOREST	Initial Stab. Min. Soil Pool Larch	kg C	Tnormal(-0,09*2;+0,09*2)
FOREST	Initial Stab. Min. Soil Pool Beech	kg C	Tnormal(-0,06*2;+0,06*2)
FOREST	Initial Stab. Min. Soil Pool Oak	kg C	Tnormal(-0,06*2;+0,06*2)

A 7-5 Definition of the used Distributions

Figure A 7-8: Definition of @Risk distributions used within the ACBM

NORMAL(μ,σ)

Applications for the normal function include the distribution of characteristics of a population (height, weight) and the size of quantities that are the sum of other quantities (because of the central limit theorum).

Density:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$$

Distribution:
No closed form

Parameters:
all μ, $\sigma>0$

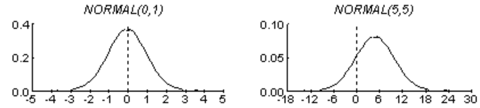
Domain:
all x

Mean:
μ

Mode:
μ

Variance:
σ

Normal Graphs:



UNIFORM(minimum, maximum)

Applications for the uniform function include quantities that vary uniformly between two values, or when only a range is known.

Density:
$f(x) = 1/(b-a)$

where a = minimum, b = maximum

Distribution:
$F(x) = (x-a)/(b-a)$

Parameters:
$a<b$

Domain:
$\text{minimum} \leq x \leq \text{maximum}$

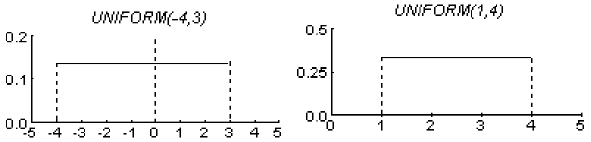
Mean:
$(a+b)/2$

Mode:
no unique mode

Variance:

$$\frac{(b-a)^2}{12}$$

Uniform Graphs:



BETA-PERT(minimum, most likely, maximum)

Used as a rough estimate in the absense of data, approximate activity time in PERT network.

The BETA-PERT distribution is only available in RISKview.

Density:

$f(x) = f_B(x', \alpha_1, \alpha_2)$

where

x'=(x-minimum)/(maximum-minimum)

f_B is the density of a BETA distribution

$$\alpha_1 = \frac{(\mu - minimum)(2 * mostlikely - minimum - maximum)}{(mostlikely - \mu)(maximum - minimum)}$$

$$\alpha_2 = \alpha_1 \frac{maximum - \mu}{\mu - minimum}$$

$$\mu = \frac{minimum + 4 * mostlikely + maximum}{6}$$

Distribution:

$F(x) = F_B(x', \alpha_1, \alpha_2)$

where x'=(x-minimum)/(maximum-minimum)

and F_B is the density of a BETA distribution

Parameters:

minimum<most likely<maximum

Domain:

minimum<x<maximum

Mean:

μ

Mode:

most likely

Variance:

$$\frac{\alpha_1 \alpha_2}{(\alpha_1 + \alpha_2)^2 (\alpha_1 + \alpha_2 + 1)} \text{*(min-max)}^2$$

TNORMAL(μ,σ,minimum,maximum)

Applications for the truncated normal function include distribution of characteristics of a population (height, weight), and size of quantities that are the sum of other quantities (because of the central limit theorem) -- constrained by truncation values.

The TNORMAL distribution is not available in BestFit.

Density:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(x-\mu)^2/2\sigma^2} \left[F_n(maximum) - F_n(minimum) \right]^{-1}$$

where

$F_n(x)$ is the Distribution function for the Normal

Distribution:

no closed form

Parameters:

all μ, $\sigma>0$, minimum<maximum

Domain:

minimum≤x≤maximum

Mean:

no closed form

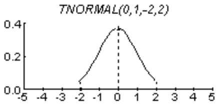
Mode:

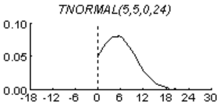
no closed form

Variance:

no closed form

Truncated Normal Graphs:





Annex 8

IIASA ACBM Database

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Annex 8 IIASA ACBM Database

The term *IIASA ACBM Database* refers to the project titled *Database for Assessment of the Austrian Carbon Balance* [*Austrian Carbon Database (ACDb)* Project hereafter], which is carried out by the International Institute for Applied Systems Analysis (IIASA). It is described in full detail in a separate IIASA Interim Report to be published in 2001.

A 8-1 Objectives

The ultimate objective of the ACDb Project is to provide support to responsible Austrian institutions in dealing with matters related to the accounting of carbon under the UN Framework Convention on Climate Change (FCCC), including the Kyoto Protocol to this Convention. To these ends, the ACDb Project pursues three (sub-) objectives. These include:

1.	Support of the ACBM:	In the form of a carbon consistent database
2.	Internationalization:	In the form of a framework that permits the placement of Austria’s carbon (or greenhouse gas) account into an international science and policy context
3.	Good Practice:	In the form of database-to-database consistency standards, identification of uncertainties, data completion for biologiocal sources/sinks, etc.

A 8-2 Project History and Setting

The project titled *System Analytical Assessment of the Carbon Balance in Austria*, which was completed in December 1997 (*Jonas, 1997*; see also *Orthofer, 1997*), aimed − as one of the first of its kind − at modeling Austria's full carbon balance dynamically in a synoptical (interdisciplinary) rather than intra-disciplinary fashion. It provided grounds for two complementary projects, the ACBM Project and the ACDb Project. The ACBM Project directs attention to quantifying and understanding the dynamics of the entire Austrian carbon system more comprehensively and in greater depth, and to supporting Austrian decision makers in identifying optimal GHG mitigation strategies (*Orthofer et al., 1999*). By way of contrast, the ACDb Project recognizes the need to respond to another, not less important outcome of the initial project, which requires that the questions of data consistency and uncertainty are treated much more rigorously and in a more fundamental context.

It can be safely stated that the ACBM Project as well as the ACDb Project are at the forefront of carbon research. Only a few studies exist that are similar to the ACDM Project and also strive for full carbon or greenhouse gas (GHG) accounting. Among them are *Nilsson et al. (2000)* with focus on Russia and *EPA (2000)* with focus on the US. Canada and Brazil are reported to be under investigation (*A. Shvidenko, 2000; pers. comm.*).

In addition, no national-scale study other than the ACDb Project exists that attempts to identify uncertainties due to data inconsistencies under full carbon accounting (FCA).[3] However, there are a number of relevant studies that do this at least in the context of partial carbon accounting (PCA)[3] or partial GHG accounting (e.g., *Heath and Smith, 2000; Rypdal and Zhang, 2000;*

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[3] This term is ambiguous in that it is not yet used in a standardized fashion.

Weiss et al., 2000; Winiwarter and Orthofer, 2000). Moreover, it can be stated that a more rigorous methodology for handling uncertainty with respect to temporal verification, as elaborated by *Jonas et al. (1999b)* within the ACDb Project and already applied (in a simplified fashion) by *Nilsson et al. (2000)*, does not exist elsewhere. Today's discussions are, at best, only beginning to address uncertainty [in the over-simplified form of trend uncertainties; (*IPCC, 2000a, b*)], but not yet verification. This is astonishing, as the Kyoto Protocol requires, among other things, clarification of the uncertainty–verification issue before the sixth meeting of the Conference of the Parties (COP-6) in The Hague in November 2000.

A 8-3 Scientific Background and Problem

The ACDb Project focuses on the following two questions:

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

Question 1 is in agreement with Objectives 1 and 3 and follows up one of the findings of Austria's first national-scale carbon research project, as mentioned above (*System Analytical Assessment of the Carbon Balance in Austria*). This finding indicated that the issues of data availability and consistency are fundamental and at least as (if not more) critical than the issues of model realization and assumptions (*Jonas, 1997, pp III, 47, 67, 94, 127, 128*).

Question 2 coincides with Objetive 2. Initially, this question was meant as a logical follow-up of Question 1, with a certain, not further specified relevance to the Kyoto Protocol. However, in the meantime it can be stated that this question alone received as much recognition and treatment by IIASA as Question 1, after it has been found going to the core of the Protocol. The Protocol requires, among other things, that emissions of specified GHG sources and sinks be assessed and verified by the time of commitment relative to the emissions in a specified base year. The relevant question that has not yet been adequately addressed will then be whether national-scale emission changes outstrip uncertainty and can be verified.

A 8-4 Scientific Approach

The calculation of uncertainties and their treatment under PCA are generally carried out using traditional mathematical statistics (e.g., *Rypdal and Zhang, 2000; Winiwarter and Orthofer, 2000)*. Biases in the data are not considered or assumed negligible. By way of contrast, the derivation of uncertainties, including biases, and their treatment under FCA, as requested under Question 1, is new; until now no instructional guide exists informing scientists how to proceed in this scientific direction.

Therefore, given this basis, the approach taken by the ACDb Project should be considered more a trial and test procedure rather than a standard technique that can be readily applied. The basic rules followed are:

1. The ACDb Project assembles officially reported or available data of many years, typically over 15, 20 or even more years backwards, depending on data availability and other criteria. So far, consistency procedures and uncertainty calculations (subjected to averaging) are done for 1990 (or some symmetric time window around 1990), in agreement with the Kyoto Protocol.

2. The ACDb Project takes a detailed (intra-database) as well as a synoptic (inter-database) view. That is, it provides intra- as well as inter-database uncertainties underlying the various databases exsisting in Austria. The latter uncertainties become apparent when using databases in a wider (integrated) context than traditionally done and they require taking biases into account, specifically, an uncertainty concept that goes beyond standard statistical methods (e.g., *NIST, 2000*).[4] The uncertainty concept applied by the ACDb Project is described in *Nilsson et al. (2000*; see also Figure 12 therein*)*.
3. The ACDb Project reports level (or total) uncertainties in the form of ($\mu \pm \sigma$) (μ = mean value; σ = standard deviation), the calculation of which is carried out in most cases on disaggregated (sub-national) levels. Data are assumed to be statistically independent because following a FCA approach makes it inherently more difficult to consider dependencies between data. This assumption which is crucial, however, can be overcome by combining mean values and standard deviations appropriately and returning again to aggregate (national) levels. It is these numbers which are believed to be justifiable. Experience to date shows that inter-database uncertainties (inconsistencies) are typically among the greatest, and are not negligible. This is also the reason why uncertainties are only reported as 1σ and not as 2σ (as typically done), because use of the latter entails more complex calculations due to biases that will only become justifiable after a successful completion of the entire project and a thorough synopsis of uncertainties on the national level.

The approach for handling uncertainty with respect to verification, as requested under Question 2, requires a general physical verification concept − which has not been widely perceived as a scientific issue. IIASA has begun developing a verification concept (*Jonas et al., 1999b; Gusti and Jeda, 2000*). It permits the calculation of verification time − that is, the time required to verify carbon (or GHG) emissions of a dynamic system where both carbon emission rates and their associated uncertainty are changing over time. However, the crucial question in the context of verification is how to define an emission change signal. This definition is not trivial and has not yet been discussed widely within and between scientific communities.

Specifically, the verification concept permits to grasp carbon (or GHG) accounting in a more general context that encompasses

- the issue of spatial completeness (project scale versus national versus global),
- the issue of temporal completeness (use of information at two points in time versus continuously),

and

- the issue of comprehensiveness (PCA versus FCA).

These issues can be addressed individually or jointly.

A 8-5 Status of Accomplishments

The timing of the ACBM and the ACDb Projects was not ideal. [The ACDb Project started five months later, i.e., in June 1999, and runs until November 2000, not considering a likely delay

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[4] NIST calls this uncertainty a *Type B Uncertainty*.

(see below).] This is the main reason why the collaboration between the two Projects – although mutually beneficial in principle – was more synergetic for some modules than for others. However, an additional delay became apparent during the treatment of Question 2 which, in fact, even increases the closer the COP-6 event draws. As already pointed out, Question 2 heads into a vastly under-explored research area, unfolding more follow-up questions (and surprises) than answers but, concomitantly, the potential to grasp carbon accounting in the more general context described above.

With respect to Question 1, the completion of work on the various modules can be summarized as follows:

FOREST:	100% (except for effortless amendments)
AGRO:	50%
PROD:	75%
WASTE:	50%
ENERGY:	just begun

Typically, the calculation of the ACDb carbon data involves four major steps:

1) check in which way and to which extent available data need to be structured (permitting minor modifications, if necessary) and disaggregated to facilitate carbon calculations;
2) derivation of carbon consistent data from material consistent data;
3) aggregation of data; and
4) adjustment of data structure to reflect model structure.

Examples of Steps 3 and 4 are given by Figures 1 (*forest 1/2*) and 2 (*forest 1/2 acbm*). They illustrate aggregated carbon flows of roundwood, fuelwood and residual wood that go from the FOREST module to other modules of the ACBM (PROD and ENERGY). The carbon flows have been made consistent with respect to two statistics that are available in Austria, the Austrian Forest Inventory and the Austrian Wood Balance. Four numbers characterize each flow: the 1990 mean value (in 10^6 tC yr^{-1}) and its mean trend (in 10^6 tC yr^{-1} / yr), and the lower and upper uncertainty of the 1990 mean value (in %). Rhombi represent nodes where Austria's wood supply and utilization data are balanced (see Figure A 8-1). In order to become consistent with the model structure of the ACBM, the rhombi are translocated into the modules PROD and ENERGY and some carbon flows are redirected (see Figure A 8-2). It is the numbers shown in Figure A 8-2 that are then exchanged with the responsible ACBM modeling teams.

With respect to Question 2, reference is made to *Jonas et al. (1999a, b)*. The verification concept developed by IIASA opens the door to a research area that has not been explored at all in light of the Protocol's requirements. As already mentioned above, the verification concept reveals the potential of generalizing carbon accounting in terms of comprehensiveness, spatial and temporal completeness. In addition, it permits to generalize our current understanding of uncertainty, limited to trend and level uncertainties, in physical terms (see Figure A 8-3). The IIASA Interim Report by *Jonas et al. (2000)* describing the policy implications evolving from the insights gained so far will appear in due course.

A 8-6 Preliminary Summary and Outlook

It can be safely said that both the ACBM Project and the ACDb Project are at the forefront of carbon research. With respect to Objectives 1 (Support of ACBM) and 3 (Good Practice), the two projects reveal many synergisms, some of which have been utilized better than others for a number of reasons. It is already foreseeable that the ACDb Project will leave room for many aspects of its work that require generalization or are not yet developed sufficientlyand which is believed to be of particular use to other countries, should they choose to carry out similar work.

With respect to Objective 2 (Internationalization), it is becoming increasingly clear that the ACDb Project touches upon an issue, the uncertainty–verification issue, which has not yet been perceived as a scientific issue. More questions (and surprises) than answers unfold but also the potential to grasp carbon accounting more generally than done so far.

It is this uncertainty–verification issue, which is believed to play an important role in the combination with models such as the ACBM. It is not unlikely that it will give rise to a completely new way of scenario development and testing.

A 8-7 References

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Figure A 8-1: Carbon flows of roundwood, fuelwood and residual wood from the FOREST module to other modules of the ACBM (PROD and ENERGY): Balancing of aggregated data.

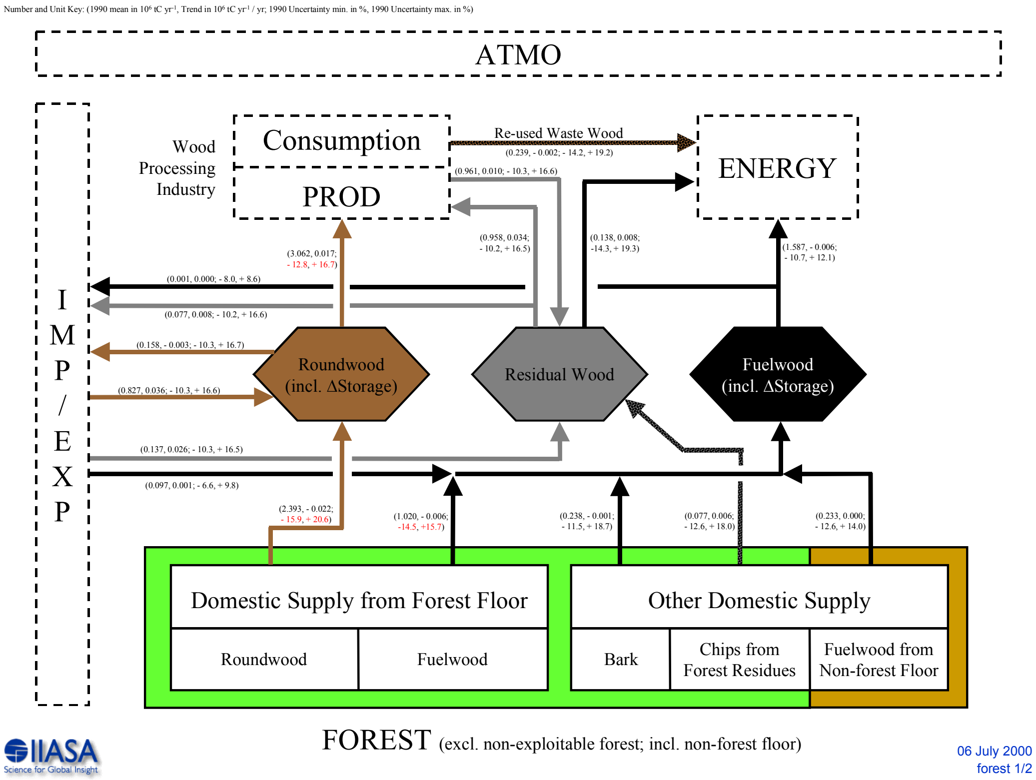


Figure A 8-2: Carbon flows of roundwood, fuelwood and residual wood from the FOREST module to other modules of the ACBM (PROD and ENERGY): Adjustment of ACDb data structure to reflect the structure of the ACBM.

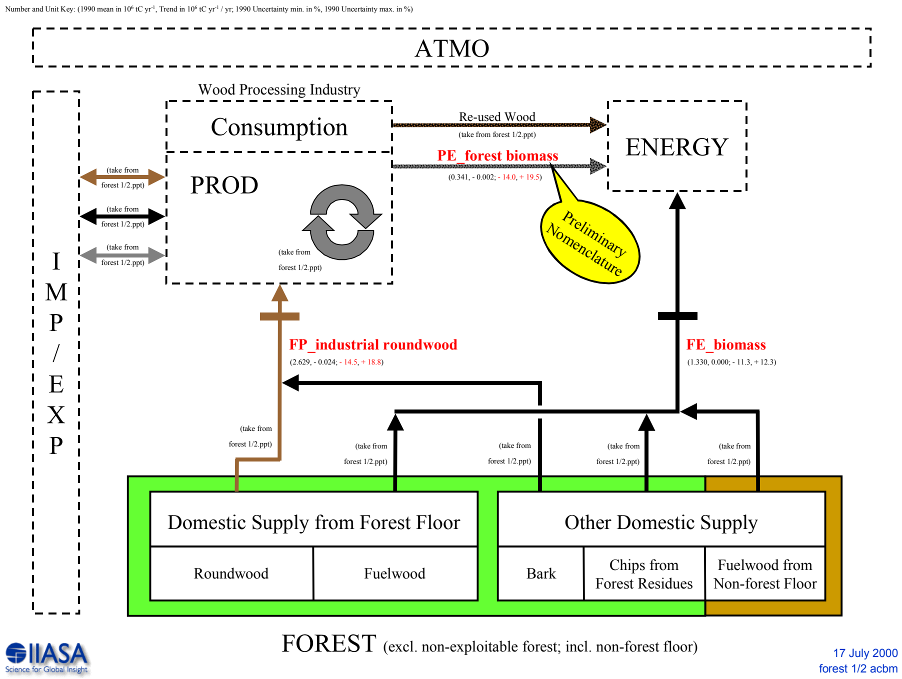
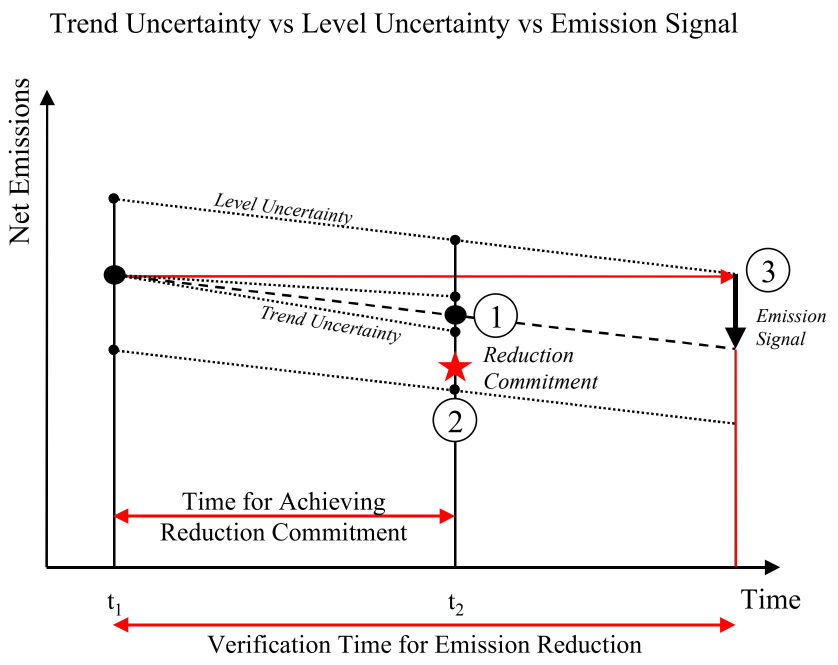


Figure A 8-3: Three conceivable examples of verification over time: Verification based on trend uncertainty (Case 1) versus verification based on level uncertainty (Case 2) versus verification based on a physical uncertainty–verification concept (Case 3).



Source: *Jonas et al. (2000)*