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The Austrian Carbon Balance Model (ACBM)

(A system analytic view of Austrians national carbon cycle.)

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Abstract:

The Austrian Carbon Balance Model (ACBM) aims to a comprehensive description and analysis of all carbon stocks and flows within the federal area of Austria as well as (carbon) interactions with the external compartments atmosphere and lithosphere. The project is based on the results of a former study about the carbon balance in Austria for the Year 1990. The developed system is a national dynamic model based on official statistical data from Austria as input values. The system dynamic model enables the user to make improved estimations and predictions for the future in comparison with the previously used method, which accounted the net release of carbon into the atmosphere, by avoiding the risks of double counting or omitting carbon sources. Furthermore we are able to analyze and understand the national carbon flux system, which supports policy makers to establish and implement policies for reducing carbon release into the atmosphere and therefore, to guarantee a sustainable development in the future. The carbon system is divided in the five main parts Agriculture, Forestry, Energy, Production and Waste, which were separately developed by relevant Austrian experts [ACBM Team].

Two scenarios were defined to show the carbon system's behavior in the future. A no major change scenario and a scenario in which we met special assumptions for carbon sequestration to meet environmental protection aims and simulate a socio-economic development towards sustainability in Austria.

A sensitivity analysis was performed to identify key input parameters for a more reliable prediction of the Austrian carbon system's future.

1 Introduction

1.1 Previous Work

The project is based on the results of a study about the carbon balance of Austria [*Orthofer 1997, Jonas 1997*]. The method developed during this study has been found useful to assess the overall behavior of the national carbon flux system. It also allows to better estimate the net release of carbon compounds (particularly carbon-containing greenhouse gases) into the atmosphere, avoiding the risks of double counting or omitting carbon sources. A carbon balance enhances the understanding of the carbon flux system, thus it enables scientists and policy makers to establish and implement policies for reducing carbon release into the atmosphere. The carbon balance approach has considerable advantages over the traditional emission inventory methodology, in which the carbon releases from given source categories are quantified and summarized one-by-one. The carbon balance method can help to understand the complexity of the intra-system carbon flows and to minimize the uncertainties that are associated with some components of a national carbon system.

Results from the previous carbon balance study have shown that in order to identify options for greenhouse gases abatement it is important to consider emissions from fossil fuels, industry and land use change as well as carbon fluxes from and to the lithosphere, from soils, from waste treatment, and from the biomass growth and use cycle. The previous project has also led to the conclusion that – in order to understand the inherent development of the national carbon system – it is important to analyze the dynamic behavior of the carbon sinks and sources, and to reduce the uncertainties associated with the carbon fluxes in agriculture and forestry.

1.2 Carbon Balances vs. Emission Inventories

A major outcome of the 1992 Rio de Janeiro UNCED Conference was the UN Framework Convention on Climate Change (UNFCCC). Article 12 of the convention requests that signature parties provide national inventories for sources and sinks of greenhouse gases, which should be updated regularly and made public [*UNFCC 1992*]. Article 12 also states that such release inventories use comparable methodologies to be promoted and agreed upon by the Conference of the Parties (COP). In 1995 (revised in 1996), the International Panel on Climate Change (IPCC) has published the recommended methods for greenhouse gas emission inventories in a guidebook [*IPCC 1996*]. The IPCC method follows basically the established instrument of air pollutant emission inventories, which have been well developed over the last decades.

Emission inventories are estimates for the release of gaseous air pollutants into the atmosphere from standardized lists of emission sources or source categories. The emissions are calculated from data or estimates on emission-generating activities, together with the respective measured or estimated average source strengths of these emission source groups. While the first emission inventories were developed for traditional urban air pollutants like SO_2 and NO_x, during the 1980's they were expanded to include other pollutants like NMVOC, and more recently, to include greenhouse gases. Thus the source group lists of emission inventory systems such as the European CORINAIR system [*EEA 1997*] were continuously updated over the past years.

However, the overall method of listing source categories together with their emissions into the atmosphere proved difficult for many carbon-containing greenhouse gas sources. First of all, the strength of carbon release into the atmosphere of many natural (such as soils) or semi-natural (such as forest product use) sources depends on the primary availability of carbon and the movement of carbon into other sectors. There are very little relevant ”emission generating activities” as a basis for calculations. Furthermore, the output of carbon into air depends not only on the input of carbon, but also on the possible storage of carbon in the various compartments (e.g. storage of carbon in energy stock, soils, and forests). Finally, traditional emission inventories that look onto emission sources one-by-one will not be able to reflect the intra-source complexity of a national carbon system. This particular shortcoming bears the danger that certain carbon emissions might be neglected and others double-counted. Such errors can be avoided if the overall flows of carbon in a national system are looked upon. Even if some sources might be quite uncertain, the view of the overall balance will allow a complete picture and an identification of relevant carbon release paths. A full carbon budget is the appropriate basis for any accounting system for terrestrial carbon [IGBP 1998]. The ACBM project uses such an alternative approach that is based on accounting of carbon flows in a given year, and over a time period of 20 years. The method should allow an identification of the carbon flow patterns and an assessment of the overall national carbon releases. Although the ACBM method is applied to the national carbon balance for Austria, in principal it should be applicable to all national or sub-national carbon accounting problems.

2 Method

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 rigour is maintained. Our aim was it to build a model that could help policy makers within their decisions. To fulfill this demand we have developed our model 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 model with data collected in the following years and this is for a data based model a very essential attribute. Some data of the model is very uncertain e.g. how many methane emissions a cattle cause, or how many feed a cattle need per year and so on.

The model has to be very flexible to meet the future demand. For these reasons and because of the circumstance that our model was developed at three different places (different Research Institutes) a modular building structure has been chosen. The Coordination was at the Austrian Research Center Seibersdorf [ACBM Team].

The overall structure of the balance is defined by the difference between carbon entering the system (inputs) and carbon leaving the system (output).

Equation 1: Balance = Inputs – Outputs

The method can be compared with the so-called national “farm gate” balances.

In the future such farm gate balances should be made in a way that all EU countries could be compared together.

2.1 Modular Model building

The overall carbon cycle in Austria is disaggregated into carbon subsystems (Figure 1). Each subsystem is divided into distinct carbon compartments, which form the basis of carbon flux analysis and calculation. There are two main types of Subsystem, as it can be seen in the Figure 1, the Outside Subsystems and the National Subsystems that differ in the following way:

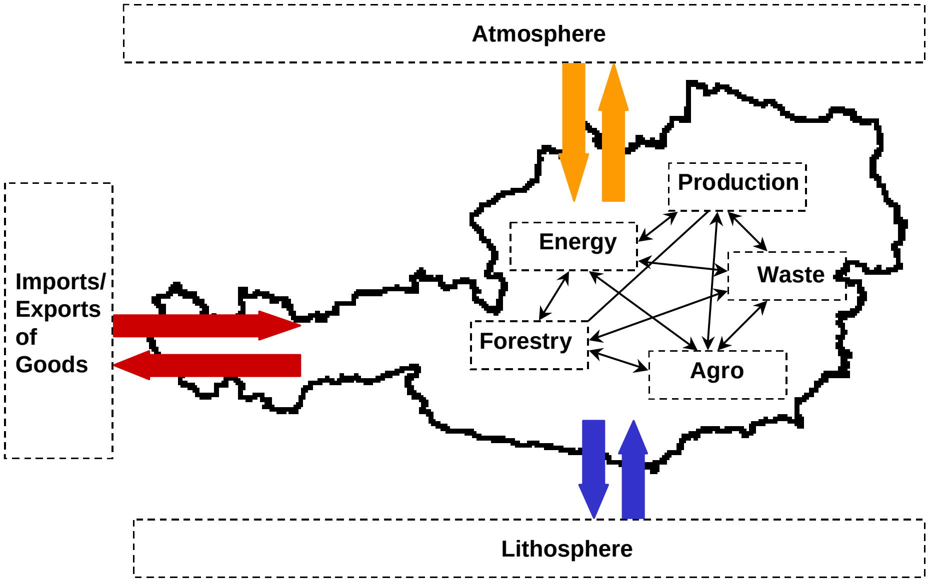

Figure 1: The ACBM overall system structure

2.1.1 The Outside Subsystems

The outside sub-system includes all „unlimited“ carbon reservoirs outside Austria, which are the atmosphere, the lithosphere and goods and products outside Austria.

- Atmosphere {ATMO}: From the atmosphere carbon is introduced into the Austrian carbon cycle through photosynthesis in the forestry and agricultural sector. On the other hand, carbon flows into the atmosphere from all subsystems. The amount of the net carbon flow from Austria into the atmosphere is finally what matters for Austria’s contribution to global greenhouse gas emissions.
- Import and Export {IMPEXP}: This subsystem represents the world outside Austria, from where carbon containing products (fuels, minerals, raw materials, consumer products,

food etc.) flow into Austria and/or *vice versa*. The fate of the goods in the outside world is not considered, as it is not within the limits of our system of concern.

- Lithosphere {LITHO}: Large amounts of carbon are stored in minerals and fossil fuels (e.g. coal, limestone minerals). From the lithosphere carbon gets into the Austrian system if carbon containing minerals are exploited for energy (fossil fuels) and products (e.g. cement manufacturing) from which carbon can be released. Only direct fluxes of carbon from the „Austrian“ lithosphere were considered; indirect fluxes (such as from coal mined in other countries and imported to Austria) are covered in the Import/Export subsystem. Carbon fluxes considered in the calculations include fossil fuel, minerals extraction and use as well as mineralization of active carbon in soils and landfills.

2.1.2 The National Subsystems

The Austrian carbon system was split into five distinct subsystems, which were dealt with separately. The subsystems correspond largely to the carbon emission sectors defined by IPCC [*IPCC 1996*]. This allows a direct comparison of magnitudes of carbon fluxes into the atmosphere from various sectors calculated by the IPCC method and by the ACBM system model. A full and exact superposition of IPCC sectors and our carbon subsystems, however, was not possible, because it was essential to match the division of our sectors with the structure of available data. The following paragraphs provide a description of the carbon subsystems:

- Agriculture {AGRO}: This subsystem includes all aspects of the growth and harvest of crops on agricultural land and the associated soil organic matter changes. Animal husbandry with its feedback interactions through use of manure is included in this module, too. The agriculture subsystem corresponds to IPCC sector 4. This subsystem has three main parts:

a) Vegetation

Within the VEGETATION part of the module five categories are represented:

- extensively cultivated grassland
- intensively cultivated grassland
- cereals, crops, fruits
- house gardens
- other vegetation (e.g. wind protection belts).

Distinguishing between the different types of vegetation allows simulating 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. The analogue dispatcher *A_harvest animals* serve for the bookkeeping of the carbon within and out from husbandry. Because 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.

b) 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.

These two main parts of living biomass are in permanent interaction with other compartments as the soil or the atmosphere.

c) Soil

Soils, like in many other ecological contexts act as an important sink. A huge amount, namely 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 alone 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 modeling of soil carbon turnover and to the description of carbon sequestration or release in and from soil, respectively.

The 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. The compartments included in the ACBM soil model are seen as the absolute minimum to facilitate all functionality's needed for soil carbon dynamics estimations and the modifications of these process by changing agricultural practice and addition of organic amendments.

For agricultural soils 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. The huge carbon pool situated below is estimated to a depth of 50 cm but not subjected to the dynamic soil modeling.

This Subsystem had been built at the Austrian Research Center Seibersdorf (ARCS).

- Energy Transformation and Use {ENERGY}: We have defined this subsystem according to the structure of an Austrian energy database [*WIFO 1996*]. It also corresponds largely to the IPCC sector 1. The energy subsystem basically reflects the carbon fluxes as contained in traditional CO_2 emission inventories. However, in addition to the IPCC sectors, we have also taken account of the non-energetic use of primary and secondary fuels (such as natural gas or refinery products), which in our system are being further transferred and accounted for in the production subsystem. The energy module is driven by the need of energy services and the demand of useful energy. The role of the energy module is to satisfy the energy demand by using different primary energy resources.

This Subsystem had been built at the Joanneum Research Graz.

- Forestry {FOREST}: This sector contains the growth of forests and the associated changes in forest litter and soils, as well as the removal of wood from the forests. This subsystem corresponds largely to IPCC sector 5, but also includes carbon changes in soil humus. Because of the large forested areas in Austria this subsystem is highly relevant in terms of carbon throughput and potential storage. The use of fuelwood and other biofuels is included in the „Energy Transformation and Use“ subsystem, while the production and use of wood products is part of the „Production and Consumption“ subsystem (see below). The module is based on the two different models FORCABSIM (Forest Development and Carbon Balance Simulation Model) from Rohner 1999 and the GORCAM (Graz Oak Ridge Carbon Accounting Model) from Schlamadinger 1996 [http://www.joanneum.ac.at/gorcam.htm]. Within the module three main carbon pools were defined:

F_VEGETATION: This pool represents the living above and below ground biomass (trees, foliage and roots). The forest ground vegetation is also considered in this pool. 9 different tree species groups and 12 age classes are distinguished in FORCABSIM.

F_LITTER: This pool includes the dead above and below ground forest biomass. C-fluxes are taken up from F_VEGETATION and released to the mineral soil pool.

F_MINERAL_SOIL: This is assumed to be the most important C-storage pool of the forest, receiving carbon fluxes from the litter compartment and releasing CO_2 emissions to the atmosphere (heterotrophic respiration and forest fire).

To propagate the age class distribution into the future a matrix formalism is used [*Rohner 1999*]. The age class vector of each tree species is repetitively multiplied by a type of “Leslie Matrix” from the left side.

The coefficients, h_{ij} of the “Leslie Matrix” ***M*** are interpreted as the transition probabilities; that is the probability that a stand of a certain age will grow older instead of being clear cut. Matrix M is of quadratic type and the dimension is given through the dimension of the age class vector. The element in the upper left corner is set to 1 due to the reasons of area constancy and maximum age.

In order to derive the coefficients in the Leslie Matrix, a certain rotation probability has to be assumed.

Equation 2: Example of matrix ***M*** with transition coefficient h_{ij} also called mortality coefficients. They represent the fraction of an age class which will be replanted (reset to the first age class) after a clear cut.

$$M = \begin{pmatrix} h_{11} & h_{12} & . & h_{ij} & . & 1 \\ 1-h_{11} & 0 & . & . & . & 0 \\ 0 & 1-h_{12} & . & . & . & . \\ . & . & . & 1-h_{ij} & . & . \\ . & . & . & . & . & 0 \\ 0 & 0 & . & 0 & . & 0 \end{pmatrix}$$

A discrete probability distribution p(t) of rotation length is assumed having a maximum probability near conventional rotation periods. The shape of the function p(t) is a Gaussian with an asymmetry caused by using two different sigma parameters. Therefore it appears that tree parameters may be varied along to get a system consistent “Leslie Matrix”: most probable rotation length, sigma1 and sigma2.

Figure 2 shows for example a possible rotation probability of an expected rotation age of 112 years and a standard deviation of 26 years for Norway Spruce in Austria. A Gaussian function with a maximum around the presumed rotation time of a species is used for the calculation of the rotation probabilities. When using different values of sigma, dependent if right or left to the maximum, asymmetric shapes can also be realized. But the sum of rotation probabilities of all age classes is always normalized to be equal to 1.

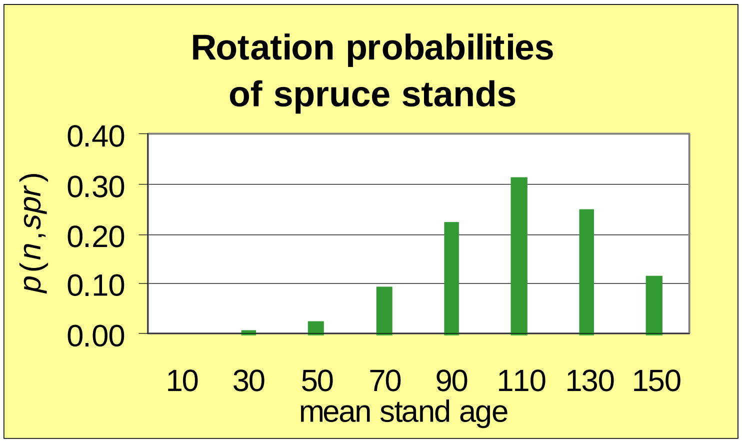

Figure 2: Example of rotation probabilities of spruce stands in Austria.

Thinning regimes (following the yield tables mentioned above), losses of growing stocks due to insects, snow breaks, or wind throws as percentage of the growing stock will be considered as well.

The calculation of the transition coefficients is done by following a reverse Markov chain:s

Equation 3: Derivation of the mortality coefficients h_{ij} from rotation probabilities p_{ij}. For simplification only the first index is denoted since only the first row coefficients matter.

$$
\begin{aligned}
h_1 &= p_1 \\
h_2 &= p_2 /(1-h_1) \\
h_3 &= p_3 /[(1-h_1)\cdot(1-h_2)] \\
&\vdots \\
h_n &= p_n / \prod_{i=1}^{n-1}(1-p_i)
\end{aligned}
$$

This Subsystem had been built at the Joanneum Research Graz.

- <u>Production and Consumption {PROD}</u>: This subsystem is rather complex. It covers the carbon fluxes from raw materials through industrial processes as well as the production and consumption of goods including food. Carbon flows into this subsystem from all other sub-systems of the Austrian carbon system, but also from the lithosphere (e.g. limestone for cement production) as well as from the imports (e.g. plastics, food products, wood and paper products, and other carbon containing goods). Short- and long-lived products are divided to consider the differences of carbon release from material decay. This subsystem does not exactly correspond to IPCC sectors 2 (industrial processes) and 3 (solvent use) because it also includes carbon fluxes from short-lived carbon containing products and from human food consumption and metabolism.

The module {PROD} includes all production sectors, which are relevant from carbon content or from energy consumption. These include food and feed, wood and paper, plastics and chemistry, textiles and leather, minerals and metal industries. Energy requirements (for transformation processes or transportation) come from the {ENERGY} module with the relevant energy mix.

Each sector is analyzed at an appropriate level of aggregation to identify cause-effect chains and to avoid the possible double counting that may occur when materials are used several times appearing several times in statistics. However considering the complexity of the productions in Austria, a certain level of aggregation had to be maintained. For the work the hereunder-listed aggregates were chosen:

Food and Feed: Meat, Fats & Oils, Cereals & Feed, Milk & Products, Fruits & Vegetables,
Sugar Products
Wood and Paper: Saw Industry, Boards, Pulp & Paper, Wood Products
Plastics and Chemistry: Cleaning, Fertilizer, Rubber, Solvents, Lubricants, Plastics, Resins, Chemicals and Bitumen
Textiles and Leather
Minerals and Metals

As the data of the selected aggregates should be able to be combined to any higher aggregation level a common structure for all branches 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 distinguishes between:

Sources
Production processes
Further manufacturing and trade of the products
Destination in consumption with estimated lifetime

This Subsystem had been built at the Institute for Industrial Ecology St. Pölten.

- Waste {WASTE}: The waste sector includes the different treatment techniques of waste products through recycling, wastewater treatment, landfilling, composting, incineration and mineralization. This subsystem is comparable with IPCC sector 6. This module comes logically after the PROD module.

  The {WASTE} module is mainly connected with the {PROD} module. Inputs from {PROD} are industrial and household wastes that are discarded after a variable 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 and need to be disposed of in landfills. Wastes that can be incinerated are transferred into the {ENERGY} module. These are either industrial wastes or residual wastes that are either directly incinerated or incinerated after MBT treatment. 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.

The modularity enabled us to change the aggregation level during the development of the model and so it is also possible to investigate some detail questions in following projects by adding compartments to the existing model structure. For example further changes of the climate were not taken into account change and influence the balance in the future.

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2.2 Structure of the Modules

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 an easy exchange of model concepts and equations between the project partners. This nomenclature contains the following elements:

Pools

A pool (level) 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. The Standard units for pools are Megatons Carbon (MTC).
Example: "*A_GRASSLAND*" is the pool of carbon biomass in grassland vegetation biomass in the module {AGRO}.

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 $\Delta t=0$ 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 ($\mathrm{MTC.yr^{-1}}$).
Example: "*AA_harvest from house gardens*" is the flow of carbon from the housegarden vegetation (*A_HOUSEGARDEN*) to the dispatcher (see below) "*A_plants for self consumption*". This flow is fully within the module {AGRO}.

Processes

Processes are model elements in which a carbon input is transformed into different carbon outputs (such as during composting of biogenic materials). The kind and duration of the process determine the nature of the output. 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 ($\mathrm{MTC.yr^{-1}}$).
Example: "*A_producing compost*" is a process in the module {AGRO} in which carbon from domestic biowaste (*AA_waste from self consumption*) is transformed into CO_2 and CH_4 that is released into the atmosphere (*AT_CO2 and CH4 from compost*) and into compost that is used for soil amendment (*AA_compost*).

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. Control variables 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 GJ per year) of agriculture in the {AGRO} module that has to be satisfied from the energy supply in the {ENERGY} module.

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 the incoming flows and the out-coming 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 ($MTC.yr^{-1}$). 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 (AA_harvest from cereals, crops and fruits) and dispatches it into an output of energy biomass (*AE_biomass for heating*), raw materials for production (*AP_harvest from plants*) and usage for feed and "Einstreu" (*AA_feed and embedding from harvest*).

2.3 Model Implementation

The project team has agreed that in order to produce an operational dynamic Austrian Carbon Balance Model that runs on a PC platform, Microsoft Excel plus Visual Basic for Application (VBA) was used as a programming tool. EXCEL/VBA has been selected instead of the system dynamic modeling software (VENSIM, STELLA, POWERSIM...) because it is a very common tool and widely established. Furthermore, most members of the project team have already good experiences with EXCEL/VBA. Another important issue was that the EXCEL/VBA system allows to integrate the five model modules, which have been developed at different research institutes, into one model through predefined interfaces. However, the project team was also aware of the advantages a system dynamic tool like VENSIM could offer, particularly the internal consistency and check of nomenclatures, the built-in verification of dimensions and units, and the standard visualization of the model structure.

The "currency" of the ACBM is carbon, i.e. model elements (pools, flows, etc.) refer to the standard units of Megatons Carbon (MTC) and Megatons Carbon per year ($MTC.yr^{-1}$). Relations between pools that do not contain carbon are only considered as long as they are important control variables. In order to be able to do a real "balancing" the model does not distinguish between different types of carbon compounds. However, the carbon flows between the modules and the atmosphere are separately calculated for CO_2- and for CH_4-carbon.

The following Figure shows a small part of the whole ACBM model scheme see also Figure 8.

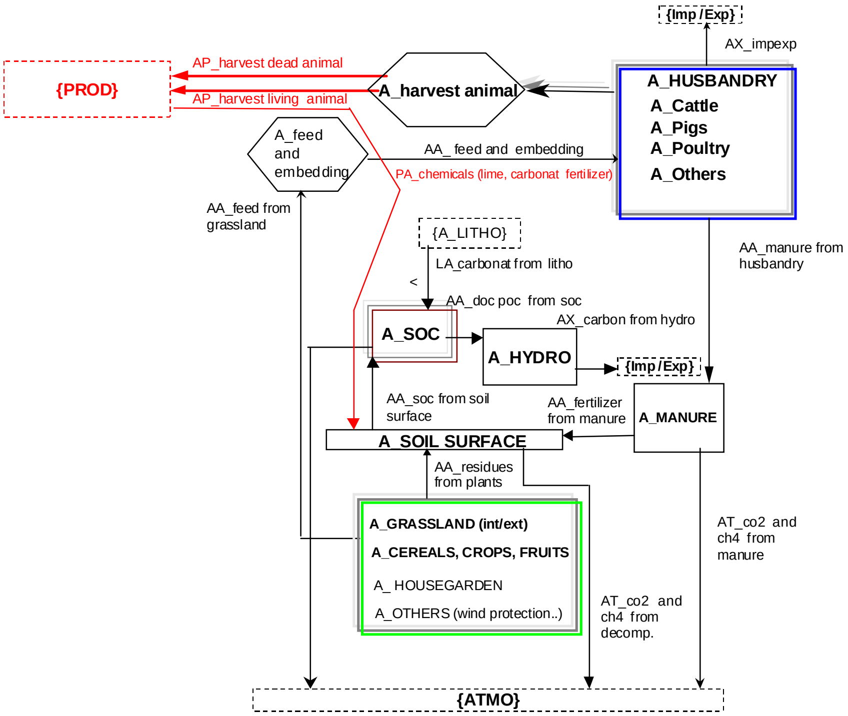

Figure 3: Small part of the whole ACBM model scheme.

2.4 Census Data based model versus conceptual model

As mentioned above we used official statistical data, census data in a Bottom up approach. Many things can be said about this kind of data, the following comments will reflect on some arguments why we have chose using them.

Even if census data is “weak”, knowing where it is so, i.e. find out uncertainties and shortcomings can make it much more valuable than using any other numbers in its place!

Fortunately, in Austria annual reporting on agricultural production has a tradition of already 40 years and, moreover the quality of reported values is continuously assessed and improved, where necessary.

In other kind of data, where higher uncertainties must be assumed, a comparison of different reports (e.g. forest inventory data with annual wood-production data) can help to elucidate inconsistencies. By introducing expert’s knowledge, most appropriate through interviewing relevant experts, which are responsible for the production of census data know best certain points of “weakness” within their statistic.

If the system is not changing too fast or unpredictably, then numerical data or statistically derived data are the only means to go, unless there is a better alternative! In the diagram Figure 4 the production over time is plotted.

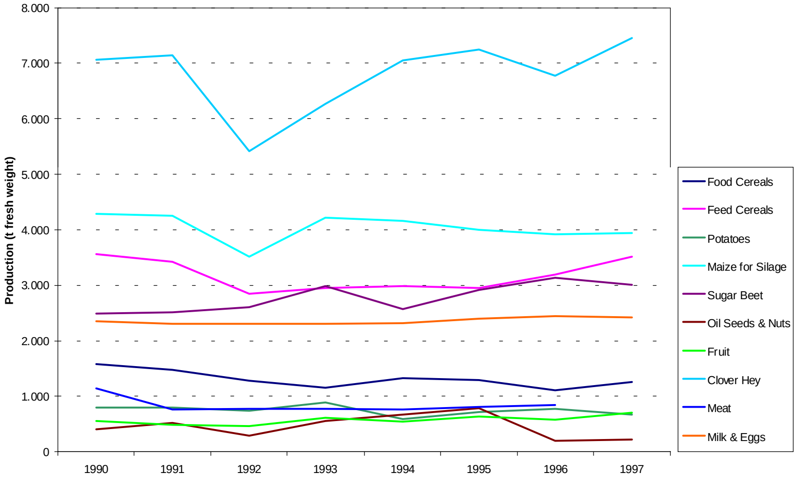

Figure 4: Production of Austrians agriculture

1992 had been a year with reduced agricultural Production because of bad weather conditions during the growing season. Here it should be said that our model doesn't count on climatic changes, but annual weather events are implicitly accounted for by not correcting extraordinary yearly data (e.g. forest harvest losses due to calamities). We took the values of the production over the time period 1990-1997. From these values we calculate coefficients for the production as a function of the cultivated area. These Coefficients were used to simulate the production for the years from 2000 to 2010 or 2020.

Driving Parameters, which are entities influencing compartments of the model like flows and pools, for two scenarios, "No major change" and "Towards Sustainability" scenarios have been developed. These driving parameters are the "screws" for changing the model behavior. As the number of 211 driving parameters can imagine it has not been very easy to develop a consistent set of driving parameters for one scenario. In the module Energy, for example, most driving parameters are efficiency coefficients for the conversion from useful energy to primary energy in the future. In this process of developing a consistent parameter set, experts from Austria had been involved.

Data uncertainties in a data based national model

The output quality of a simulation can never be better then the quality of the input data it consists of, especially in a data based model. One of the greatest problems had been the circumstance that it turned out to be very difficult to get a consistent database. Different data sources contain different values for the same entities. So we had to deal with uncertain values. Because of the huge amount of flows and pools we could not consider all the uncertainties within a fault propagation, but for the essential flows and pools we made a sensitivity analysis by use of @risk, a special add-in software for Excel. This enables us to deal with probability distribution functions as the most famous and ubiquitous bell-shaped Gaussian or "normal" distribution. Trough this analysis we are able to say if our two scenarios will differ significantly or due to the great uncertainties in the data no significant difference in 10 years emerges. The uncertainties tend to become more and more necessary for the validation of complex models [CIPRA 2000]

2.5 The concept of Driving Parameters

Driving forces play an important role for the dynamic control of the Figure 5). Driving forces can be highly aggregated (e.g. “economic development”) or very detailed (“development of vegetarianism”). These driving forces will need to be “translated” into operational driving parameters that will the act as a flow control (e.g. “economic development” expressed as % growth of the Gross National Product (GNP) or “development of vegetarianism” expressed in % of the population).

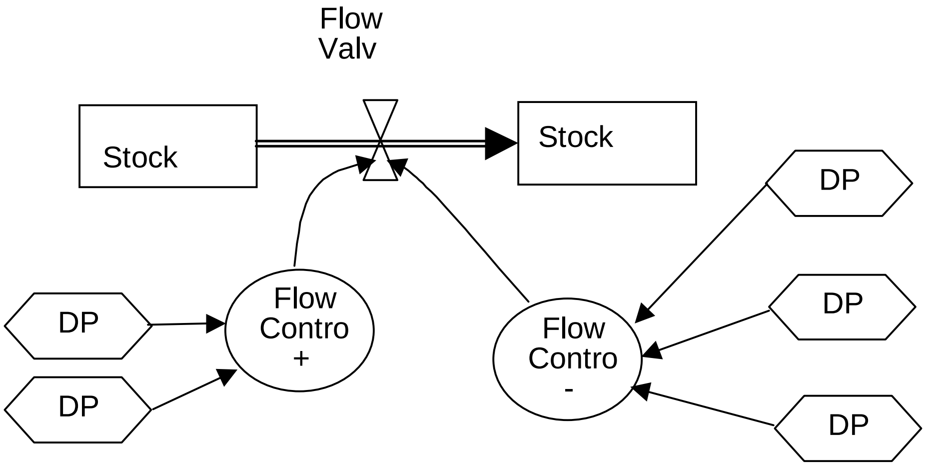

Figure 5: Scheme of the control of a flow between two stocks through positive and negative flow controls and driving forces (DP = driving parameter).

The dynamic modeling had been done in two steps:

<u>Ex-post modeling of the past</u>: the development of the carbon system in Austria modeled for the period 1990-1998 using “real” data. This step had been used to establish empirical relations between flows and their controlling parameters, and to assess and quantify the influence of driving parameters. The objective was to adjust the dynamics of the simulation for this period to the actual statistical data through “tuning” of parameters.
<u>Anticipative modeling of the future</u>: the projected development of the carbon cycle has been modeled for the period 1999-2010 using the empirical parameters from the past that had been extrapolated from the 1990-1999 trends and weighted with anticipated changes of the driving parameters.

3 Results

Through the two different approaches, Bottom up and Top down, we got a model with a modular architecture at a certain aggregation level, as simple as possible and as detailed as necessary to reach our aim (Figure 8). To understand such a complex model, like a national carbon cycle, it is very necessary not to go to deep into detail because in that case on the one hand no national data is available and on the other hand the uncertainties of the data will propagate so that the insight into the system behavior would be less then 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. Is the step to big then the dynamical behavior could not be shown, is the step to small then the error from the calculation could become very big. 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 more effort. A modular building approach shrinks this effort.

For a first approximation we took a boundary value of 0.1 MTC/yr for flows which should be counted. But in some cases, as e.g. in the WASTE module, it has been necessary to take smaller flows into account because they were important for a closed carbon cycle.
Figure 3 shows a part of the complex model structure from the module agriculture. The model has many feedback loops as for example between the plant production, which supplies the husbandry with feed and the husbandry itself supplies the soil with manure. If a smaller amount from 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 on the soil and the plant production would be reduced if the missing nutrition for the plants would not be compensated with mineral fertilizers. So there is a positive feedback in this circle. The following picture illustrates this.

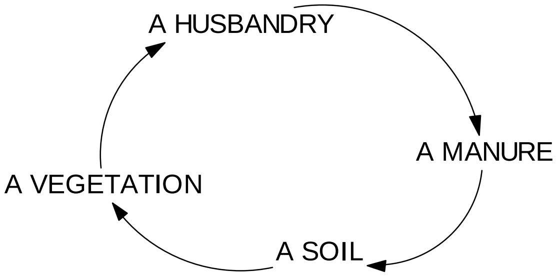

Figure 6: Feedback loop of Plant production and Husbandry

Many such loops can be found in the whole system. Such causal loop diagrams (CLD) help to understand the system behavior in a better way. 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 on to the stocks and flows. And for the analysis of the dynamical behavior such CLD help to learn more about the whole system. Often knowledge has to be visualized for understanding.

The model describes the main fluxes over a year and the change of these fluxes till the year 2010 or longer. Due to the great uncertainties in the underlying data the simulation for more then 20 years won't produce valid results.

The next Figure shows a comparison of the quantities of the main carbon fluxes in Austria.

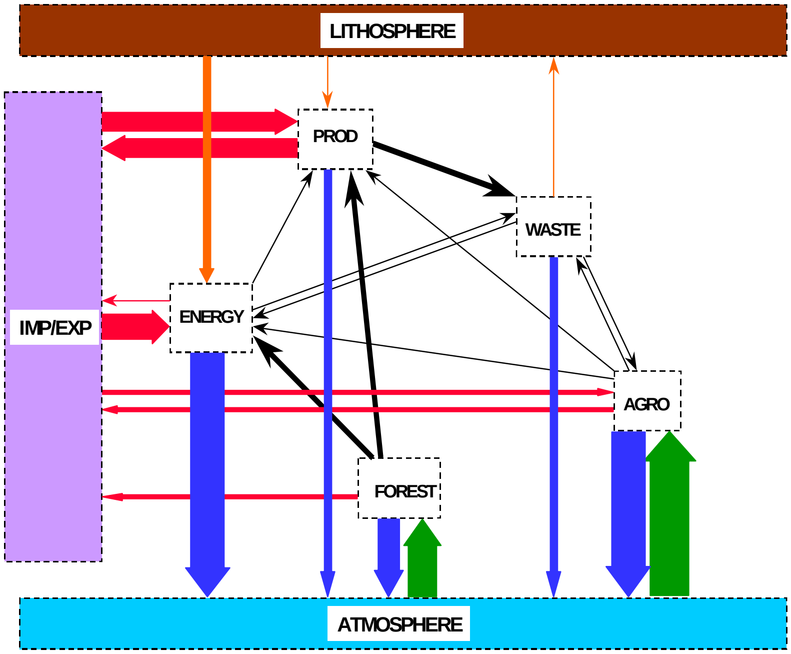

Figure 7: Quantity of main fluxes within the Austrian Carbon Balance

The main fluxes into the atmosphere are from the Energy module. The main fluxes from the atmosphere are, into the FOREST and AGRO module.

We also got a database for the national carbon balance with more then 500 elements with census data for the years 1990 to 1998 and data from the simulation for the two scenarios from 1998 to 2010.

4 Diskussion

More often Complex Systems can not be solved analytically, for such problems a numerical computer model can help to understand the system behavior.
A problem, which never can be solved in a satisfactory way, is to determine how far to the details of a complex system a model maker should go.
We have used census data with its inherent uncertainties and we normally only count carbon fluxes bigger than 0.1 MTC/yr. It could be that for future demand we have to move this boundaries or to add some compartments to the model as for example economic parameters (oil price etc.).
The modular building approach, which we have used, makes an adaptation to fulfill these demands possible.
Further Research has to be done to determine accurate cause - effect relationships for many flows. For example how is the exact effect of a decrease in the meat consume to the Austrian eating habit.
The developed model gives first estimates about the dynamic of such complex questions.

The uncertainty of the census data has to be reduced. To meet these demand a project has been launched. Results from this investigation will be applied to the ACBM model to reduce the uncertainty of the simulation output.
A major result of the project has been found during the building process of the model itself, because of the gain of insight in the carbon system dynamic. But we know that our model only can be one step in a long way to understanding such complex dynamical behavior.

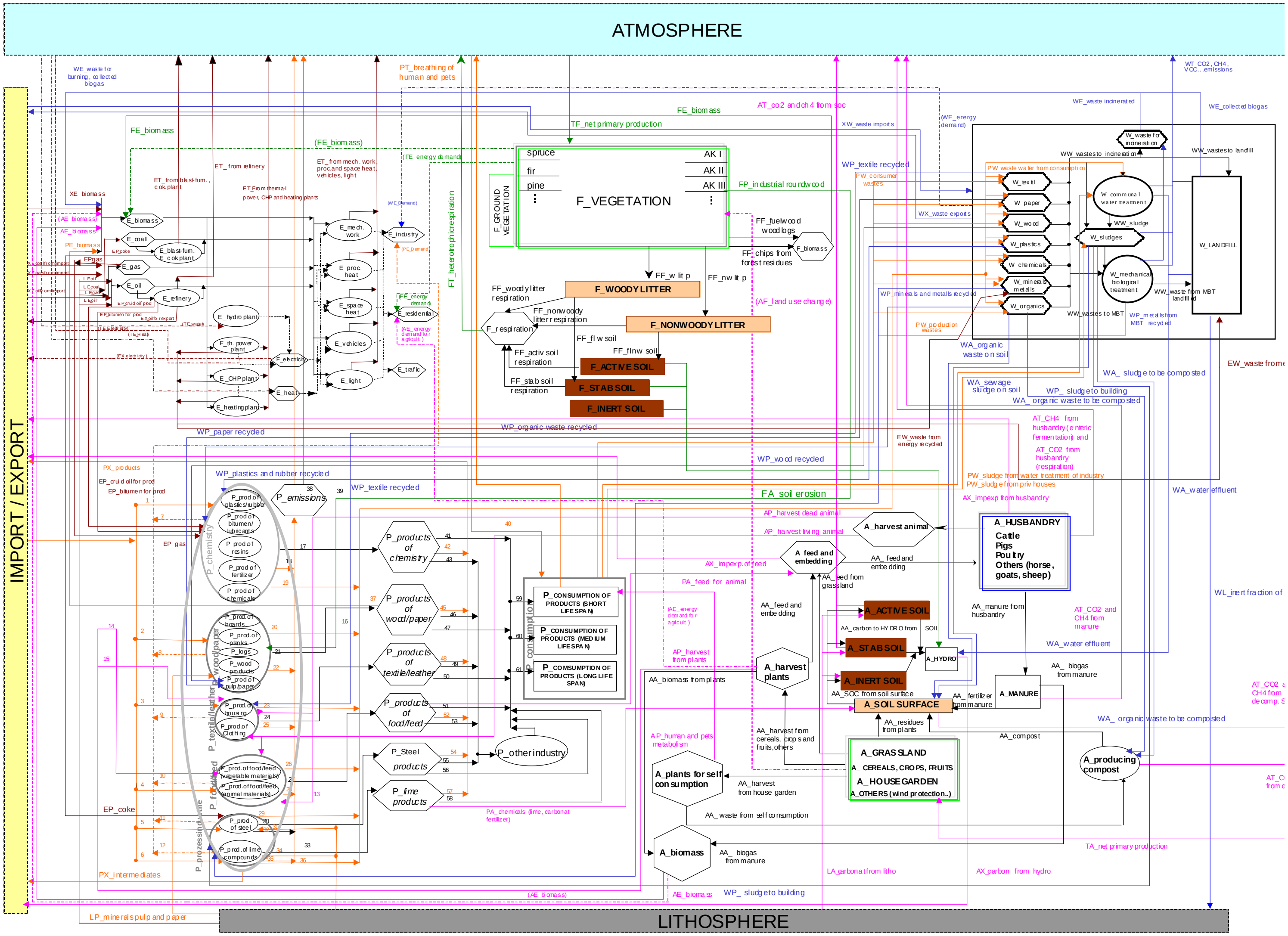

Figure 8: Model Scheme

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