CO2FIX V 3.1 - A modelling framework for quantifying carbon sequestration in forest ecosystems

Dedication

We dedicate this document to the memory of José Garza Caligaris, better known as 'Pepe'. Pepe was a member of the CASFOR project since its inception in 1998. As part of the UNAM team, he was in charge of programming the first two versions of the CO2FIX model. He also set up the basic software structure for the new versions of the program. Pepe was energetic, imaginative, incredibly hard working and insightful. He had a critical mind, always looking to the most efficient path to solving complex issues. Pepe was full of joy and had a strong social commitment. Above all, he was a wonderful friend and a great companion. We will always miss him.

Acknowledgements

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ABSTRACT

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This report describes the conceptual approach of the CO2FIX V 3.1 model, as well as its implementation and numerous examples. This stand level simulation model is a tool which quantifies the C stocks and fluxes in the forest biomass, the soil organic matter and the wood products chain. Included are also a bioenergy module, a financial module and a carbon accounting module. The model is applicable to many different situations: afforestation projects, agroforestry systems, and selective logging systems. The model is freely available from the web, together with numerous examples. The model has many users. The two earlier versions of the model have been downloaded already almost 2000 times.

Keywords: afforestation, agroforestry, bioenergy, carbon accounting, Carbon sequestration, CDM, forest management, forest simulation model, Kyoto protocol

Disclaimer

By having clicked on the 'I agree' button when you registered for CO2FIX you have agreed to the license conditions mentioned below.

CO2FIX V 3.1 software can be downloaded free of charge and used exclusively for the purpose of research, education or real-life application in carbon sequestration projects. CO2FIX V 3.1 may not be distributed to third parties in any other way than by downloading the original software from this web site. CO2FIX V 3.1 software may only be used in the downloaded form. Any modifications or further developments of the software can only be done after having consulted the developers.

Use of the model should be acknowledged in publications by making reference to both of the following publications:
- Schelhaas, M.J., P.W. van Esch, T.A. Groen, B.H.J. de Jong, M. Kanninen, J. Liski, O. Masera, G.M.J. Mohren, G.J. Nabuurs, T. Palosuo, L. Pedroni, A. Vallejo, T. Vilén, 2004. CO2FIX V 3.1 – A modelling framework for quantifying carbon sequestration in forest ecosystems. ALTERRA Report 1068. Wageningen, The Netherlands.
- Masera, O., Garza-Caligaris, J.F., Kanninen, M., Karjalainen, T., Liski, J., Nabuurs, G.J., Pussinen, A. & de Jong, B.J. 2003. Modelling carbon sequestration in afforestation, agroforestry and forest management projects: the CO2FIX V.2 approach. Ecological Modelling 164: 177-199.

Please send information about publications in which you have used CO2FIX to the developers of the software:
G.J. Nabuurs, ALTERRA, PO Box 47, NL 6700 AA Wageningen, The Netherlands.

Except for the enclosed case study forest types, the user of CO2FIX is solely responsible for the quality of parameterisation data. Neither the authors of the model, nor those of the Windows version assume responsibility for damages caused directly or indirectly from the use of the program or by the application of results derived from it.

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Contents

Summary

The CO2FIX stand level simulation model is a tool which quantifies the C stocks and fluxes in the forest biomass, the soil organic matter and the wood products chain. The model calculates the carbon balance with a time-step of one year. Basic input is stem volume growth and allocation pattern to the other tree compartments (foliage, branches and roots). Carbon stocks in living biomass are calculated as the balance between growth on the one hand and turnover, mortality and harvest on the other hand. Litter from turnover and mortality processes and logging slash form the input for the soil module. The organic matter decomposes and transforms into soil organic matter. The harvested stemwood is tracked through processing lines via product classes with different lifespans to its final fate: decomposition in landfills or dumps, or used as a source for bioenergy. The bioenergy module calculates the benefits for greenhouse gas emissions of the use of biomass instead of fossil fuels. Fuel sources for bioenergy can be either logging slash or industrial residues (processing losses or discarded products). In the financial module, costs and revenues can be specified to get an indication of the profitability of the project. In the carbon accounting module, the user will get an indication of the amount of credits that can be generated with the project according to different types of crediting systems (tCERs and lCERs for CDM-AR projects and the stock change method for other projects). The model produces output in tabular and graphic forms. It allows estimating the time evolution at the stand level of the carbon stored in different pools of the system. The CO2FIX model V 3.1 is applicable to many different situations: afforestation projects, agroforestry systems, and selective logging systems. The model is freely available from the web, together with numerous examples. The model has many users. The two earlier versions of the model have been downloaded already almost 2000 times.

1   Introduction

The terrestrial biosphere plays an important role in the global carbon cycle. On average in the 1990's it absorbed 2.3 billion tonnes C y^{-1} which is 36% of annual fossil fuel emissions (IPCC, 2001). This notion continues to drive scientific research on the temporal evolution of the sink, the location of the sink across biomes and the (im)possibilities of management to influence it.

Also, international emission reduction policies continue to center around the role of the biosphere. Main agreement was reached at COP VIb in Bonn, and elaborated at COP VII in Marrakesh in 2001. Since then, the Intergovernmental Panel on Climate Change (IPCC) has been asked to prepare Good Practice Guidance (GPG) on reporting greenhouse gases of the Land Use, Land Use Change and Forestry Sector, an elaboration of the 1996 Revised IPCC Guidelines. This GPG was adopted in October 2003. Furthermore, the policy arena has set up a draft document how to deal with permanence, leakage, and accounting of projects falling under the Clean Development Mechanism. Pending these decisions, and real life projects taking shape now e.g. under the Prototype BioCarbonFund of the World Bank, there is a great need for harmonised tools to quantify the carbon balance of forested ecosystems.

To address these issues and provide insight in the temporal dynamics of carbon sequestration, CO2FIX V 1.0 was designed for even-aged monospecies stands (Mohren and KleinGoldewijk, 1990; Nabuurs and Mohren, 1995). Under the first CASFOR project, this version was further developed into a windows based user friendly programme and released through the world wide web in June 1999 (V 1.2, Mohren et al. 1999). Since then more than 1000 users from over 75 countries have downloaded the first version and applied it in several studies (see for example Nabuurs and Schelhaas, 2002; Lettens et al., 2003; Paul et al., 2003; Gabus, 2003), or further developed it (Richards and Evans, 2000; Richards, 2001). In the meanwhile, the model was developed further by the CASFOR team on the following points:
- The ability to simulate multi-species and unevenaged stands in multiple cohorts
- The ability to parameterise the growth also by stand density
- The ability to deal with inter cohort competition
- Allocation, processing lines, and end-of-life disposal of harvested wood
- Soil dynamics
- The ability to deal with a wider variety of forest types including agro-forestry systems, selective logging systems, and post harvesting mortality
- Output viewing charts.

This resulted in the release of version 2.0 in October 2001. Until November 2004, almost 2000 users from over 75 countries have downloaded it. A description of the version 2.0 model can be found in Nabuurs et al. (2002) and Masera et al. (2003).

Within the CASFOR II project, the current V 3.1 has been developed. The major points of improvement with regards to V 2.0 are:
- Inclusion of a financial module to calculate costs and revenues

- Inclusion of a carbon accounting module to calculate carbon credits
- Bio-energy module.

The new version should give developers of LULUCF projects a user friendly tool to asses the amount of credits that can be earned under the different crediting schemes, and to provide an estimate of discounted costs and benefits made per carbon credit earned. Furthermore, a wider variety of example cases is released with V 3.1, including non forested ecosystems. Chapter 2 describes the concepts of the model. How to download and operate V 3.1 can be found in Chapter 3. Chapter 4 contains a description of the examples that are delivered with the model. Chapter 5 shows how to parameterise some special cases, such as disturbances and coppice systems. Chapter 6 discusses some aspects on accuracy of the model. For a quick start, a separate manual is delivered with the model as pdf file, based on the Chapters 2, 3 and 4 from this description. Since Chapter 3 is basically written for the manual, some overlap exists between Chapter 2 and 3, mainly in the modelling principles.

Within the CAFOR II project, a new model will be developed that interacts with CO2FIX V 3.1 to be able to simulate whole landscapes instead of forest stands only. This model version, called CO2Land, is to be released in end of 2004, and will be available via the project website.

2 Conceptual description

2.1 Model structure

The CO2FIX V 3.1 is an ecosystem-level simulation model that quantifies the C stocks and fluxes in the forest using the so-called full carbon accounting approach, i.e. calculating changes in carbon stocks in all carbon pools over time (Noble et al., 2000). It has been programmed in C++ using an object-oriented programming environment. The model is divided in six main modules (Figure 2.1):
- biomass module
- soil module
- products module
- bioenergy module
- financial module
- carbon accounting module

The total carbon physically stored in the system at any time (CT_t) is considered to be

$$CT_t = Cb_t + Cs_t + Cp_t \qquad (Mg\ C/ha) \qquad (1)$$

where
Cb_t is the total carbon stored in living (above plus belowground) biomass at any time 't' (Mg C/ha),
Cs_t is the carbon stored in soil organic matter (Mg C/ha), and
Cp_t is the carbon stored in wood products (Mg C/ha)

The bioenergy module does not represent a carbon stock, but calculates the effect of using wood or wood waste for the generation of energy. In that case, fossil fuels are replaced by CO_2-neutral fuels, and can thus be regarded as an avoided emission. These avoided emissions can be expressed in carbon equivalents and added to the total stock in the system to calculate the total effect of the simulation on the atmosphere.

$$A = CTt + Cbio_t \qquad (MgC/ha) \qquad (2)$$

where
A is total atmospheric effect, and
$Cbio_t$ is avoided emissions due to bioenergy use

The carbon accounting module keeps track of all fluxes to and from the atmosphere and determines the effects of the chosen scenarios, using different carbon accounting approaches. The financial module uses costs and revenues of management interventions to determine the financial profitably of the different scenarios. The model simulates stocks and fluxes of carbon in trees, soil, and -in case of a managed forest- the wood products, as well as the financial costs and revenues and the carbon

credits that can be earned under different accounting systems. Stocks, fluxes, costs, revenues and carbon credits are simulated at the hectare scale with time steps of one year. Each of these modules is described separately in the following sections.
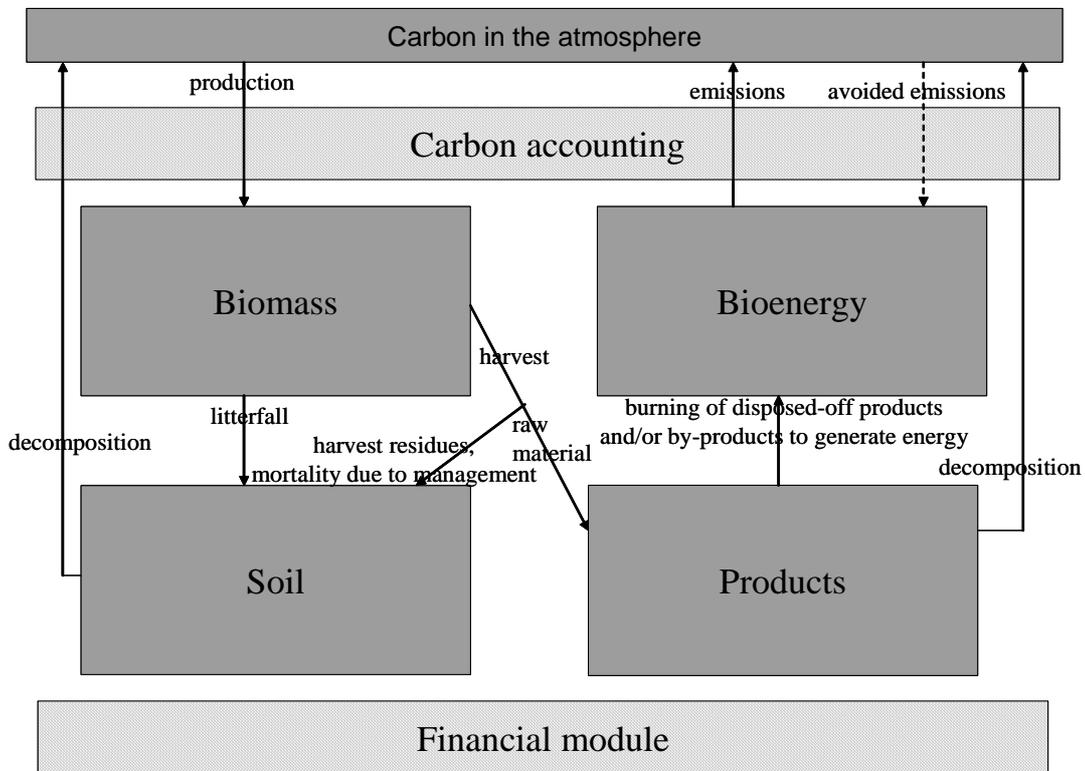
Figure 2.1. The modules of CO2FIX V 3.1.

2.2   Biomass module

2.2.1   The cohort approach

The carbon stocks and flows in the forests' living biomass (above- and belowground) are estimated using a 'cohort model' approach (Reed, 1980). Each cohort is defined as a group of individual trees or species, which are assumed to exhibit similar growth, and which may be treated as single entities within the model (Vanclay, 1989, Alder and Silva, 2000). These cohorts may be, for example: a) successional groups in a natural forest (e.g. pioneers, intermediate, and climax), b) species in a mixed forests (e.g. mixed pine-oak forests); and c) strata in a multi-strata agroforestry system (e.g. understory, middle layer, upper layer). The carbon stored in living biomass (Cb_t) of the whole forest stand, can then be expressed as the sum of the biomasses of each cohort, i.e.,

$$Cb_t = \sum Cb_{it} \qquad \text{(Mg C/ha)} \qquad (3)$$

where Cb_{it} is the carbon stored in the living biomass of cohort 'i' at time 't' (Mg C/ha).

For each new time step, Cb_{it} is calculated as the balance between the original biomass, plus biomass growth (Gb_{it}), minus the turnover of branches, foliage and roots (T_{it}), minus tree mortality due to senescence (Ms_{it}), minus harvest (H_{it}) minus mortality due to logging (Ml_{it}), i.e.,

$$Cb_{it+1} = Cb_{it} + Kc [Gb_{it} - Ms_{it} - T_{it} - H_{it} - Ml_{it}] \qquad (MgC/ha) \qquad (4)$$

where Kc is a constant to convert biomass to carbon content (Mg C per Mg biomass dry weight).

2.2.2 Biomass growth

CO2FIX distinguishes four tree biomass compartments: stem (including bark), foliage, branches and roots. In order to simulate Gb_{it} the model uses as input the growth rate of stem volumes (gross annual increment), which can be derived from yield tables. From this growth rate of stem volumes, growth rates for foliage, branches and roots are calculated, using time-dependent allocation coefficients. Hence, the model uses stem volume growth (in $m^3 \ ha^{-1} \ yr^{-1}$) as the main input, and uses an allometric approach to derive biomass increment of the main biomass components from stem volume growth. These growth rates are later modified by the interactions of the cohort within itself and with other cohorts. To adjust for differences in site quality, yield tables derived for good, medium and poor site conditions may be used and other growth related parameters modified accordingly (Nabuurs and Mohren, 1995). Mathematically,

$$Gb_{it} = (Kv_i \ Ys_{it} \ (1+\Sigma \ (F_{ijt}))) * Mg_{it} \qquad (Mg \ ha^{-1} \ yr^{-1}) \qquad (5)$$

where
Kv_i is a constant to convert volume yields into dry biomass (basic wood density, in Mg dry biomass per m^3 of fresh stemwood volume) for each cohort 'i'
Ys_{it} is the volume yield of stem wood for each cohort 'i' ($m^3 \ ha^{-1} \ yr^{-1}$),
F_{ijt} is the biomass allocation coefficient of each living biomass component 'j' (foliage, branches, and roots) relative to stems, for each cohort 'i' at time 't' (Mg per Mg stemwood), and
Mg_{it} is the growth modifier due to interactions among and within cohorts (dimensionless).

The model provides two alternative ways to define stem growth of each cohort: a) as function of tree or stand age (conventional yield tables), and b) as a function of the cohort total and maximum aboveground biomass. The latter input option has been added because in tropical forests often diameter dependent instead of age dependent growth of trees is used.

In order to be able to model the carbon stored and accumulated in multi-cohort stands, CO2FIX modifies the growth of each cohort due to tree interactions. This is because tree growth in a cohort is influenced by the presence of other trees.

Interaction effects can range from decreased growth (competition) via no effect to increased growth (synergic effects). The major type of interaction is competition. For a cohort, the interaction can be caused by other individuals in the same cohort, or by individuals of other cohorts.

There are various ways of modeling competition. In gap models, 'growth modifiers' are used for this purpose (Botkin et al., 1972). It is assumed that trees grow at a maximum rate under optimal conditions, but that this growth can be affected by biotic and abiotic conditions of the environment. In growth and yield models, the growth modifier is usually defined as a function of stand-basal area or as a function of other variables indicating stocking density of the stand (Peng, 2000; Monserud and Sterba, 1996). The modifier values range from 0 (no growth at all), via 1 (i.e., growth is not reduced) to more than 1, when there are synergic effects (i.e, where growth is higher in the mixture than in the case of each cohort alone). This is relevant for multi-species and multi-strata situations (e.g. Beer et al., 1990).

In this model a single parameter (Mg_{it}) is used to simulate the influence of the same cohort or the influence of other cohorts on the growth of the cohort in question. Mg_{it} is defined as a function of total biomass of the stand. The model provides two basic options for modelling the interactions between and within the cohorts: (a) Competition of a cohort as a function of total stand biomass (i.e. total aboveground biomass of all cohorts in a stand at any time ('B_t', Mg DM ha^{-1}) relative to the maximum total stand biomass of all cohorts ('B_{max}', in Mg DM ha^{-1})). In this case, the interactions of this cohort with all the cohorts combined, including the cohort in question, is modelled. (b) Interactions of the cohort in question as a function of the relative biomass of each other cohort separately. Mathematically, we can express Mg_{it} either as

$$Mg_{it} = f\left(\frac{B_t}{B_{max}}\right) \qquad \text{(dimensionless), or} \tag{6}$$

$$Mg_{it} = \prod Mg_{ikt} \qquad \text{(dimensionless)} \tag{7}$$

where Mg_{ikt} is the dimensionless growth modifier function of each cohort 'i', relative to each of the other cohorts 'k' and

$$Mg_{ikt} = f\left(\frac{B_{it}}{B_{imax}}\right) \qquad \text{(dimensionless)} \tag{8}$$

where B_{it} and B_{imax} are the aboveground biomass of each cohort 'i', and the maximum aboveground cohort biomass, respectively. Thus, if two cohorts are present, we have to include four possible growth modifiers, if three cohorts are present, then potentially nine growth modifiers might be defined, and so on.

2.2.3 Tree mortality due to senescence

Mortality due to senescence can be estimated as a function of tree age or as a function of the relative biomass (standing biomass divided by the maximum stand biomass).

$$Ms_{it} = f(age) \text{ or } Ms_{it} = f(\frac{B_{it}}{B_{i\,max}}) \qquad \text{(dimensionless)} \qquad (9)$$

where Ms_{it} is the cohort mortality due to senescence of cohort 'i' at time 't'.

In the first case, it is assumed that all trees have a maximum age, and that the mortality (i.e. the probability of dying) increases when the age of the stand approaches the maximum age. In some situations, there may also be high initial mortality, for instance, of pioneer species in a natural succession (Vanclay, 1989). If data of mortality related to age is not available, a typical situation for tropical natural forests, the mortality can be modelled as a function of relative cohort biomass. The mortality fraction is applied equally to all living biomass compartments: stems, foliage, branches and roots.

2.2.4 Turnover

In addition to tree mortality, an accurate estimation of carbon dynamics in the other biomass compartments needs to account for the turnover of foliage, branches, and roots of the remaining trees. This turnover is also very important to adequately model the carbon dynamics of soil organic matter. We model the turnover for each cohort (T_{it}) as the sum of the turnovers of each component 'j', which in turn is simply the existing biomass of the particular component 'j' multiplied by a decay -or turnover- constant (Kt_{ij}). Mathematically,

$$T_{it} = \sum B_{ijt} * Kt_{ij} \qquad \qquad \text{(Mg C ha}^{-1}\text{)} \qquad \qquad (10)$$

where Kt_{ij} ranges between 1 (i.e., all the component biomass is lost during the year) to 0.

There is no separate compartment for coarse roots and fine roots. This has implications for the turnover rate of the root compartment. Generally the turnover of fine roots is much higher than coarse roots, but the biomass of coarse roots increases during a rotation, whereas the biomass in fine roots shows less variation. In case of short rotations, there will be relatively more fine roots than in case of long rotations. Since turnover of fine roots is higher, total root turnover should be higher under short rotations than under long rotations. However for representing the soil dynamics in greater detail, this one root compartment is distinguished in coarse roots and fine roots at the time of turnover. The fractions of these two are assumed the same as the ratio between branches and foliage litter at that time.

2.2.5 Harvesting

If the particular forest ecosystem under analysis is managed, part or all of the tree biomass is removed through thinnings, selective logging or clear-cutting. This harvested biomass is subtracted from the existing biomass, and is allocated to the products and soil modules (see the chapters on soil organic matter and wood products below). Harvest in year 't' in cohort 'i' is defined as a fraction of the existing biomass in that cohort (fH_{it}). This fraction is applied to all components 'j' (foliage, stems, branches, roots). Total harvested biomass (H_{it}) is then calculated as:

$$H_{it} = \sum (B_{ijt} * fH_{it}) \qquad \text{(Mg C ha}^{-1}) \qquad (11)$$

2.2.6 Mortality due to logging (harvesting) damage

Forest logging operations can increase the mortality of the remaining trees. This damage depends very much on the type of forest and the type of technology and methods used in logging. Mortality due to logging is directly related to the intensity of logging, which can be expressed as the number of trees, basal area, volume, or biomass logged.

Also, the logging may cause mortality several years after the operation (Pinard and Putz, 1997). In many cases, the initial mortality is high during the first years after the logging, and the mortality decreases gradually, reaching zero in 10-20 years, depending on the forest type and technology used (Pinard and Putz, 1997). In the CO2FIX model, we use a logging damage mortality coefficient (Kl_{it}) as a linear function of time (years after logging, 'p') with three parameters: (a) initial mortality (Mo_i), (b) duration of the damage (π), and (c) intensity of the initial logging (Io_i). Mathematically,

$$Ml_{it} = B_{it} * Kl_{it} \qquad \text{(Mg C ha}^{-1}) \qquad (12)$$

where

$$Kl_{it} = f(I_{0i}, M_{0i}, \pi, p) \qquad \text{(Mg C ha}^{-1}) \qquad (13)$$

2.3 Soil module

2.3.1 Applicability

The dynamic soil carbon model Yasso (Liski et al., in prep., http://www.efi.fi/projects/yasso/) is used as the soil module of CO2FIX. The model describes decomposition and dynamics of soil carbon in well-drained soils (soils in which poor drainage does not slow down decomposition). The current version is calibrated to describe the total stock of soil carbon without distinction between soil layers. The model can be applied for both coniferous and deciduous forests. It has

been tested to describe appropriately the effects of climate on decomposition rates of several litter types in a wide range of ecosystems from arctic tundra to tropical rainforest (Liski et al., 2003a, Palosuo et al. in prep.).

2.3.2 Structure

The soil module consists of three litter compartments and five decomposition compartments (Figure 2.2). Litter is produced in the biomass module through biomass turnover, natural mortality, management mortality, and logging slash (see section 2.2 for a description of these processes). For the soil carbon module, the litter is grouped as non-woody litter (foliage and fine roots), fine woody litter (branches and coarse roots) and coarse woody litter (stems and stumps). Since the biomass module makes no distinction between fine and coarse roots, root litter is separated into fine and coarse roots according to the proportion of branches and foliage litter. Each of the litter compartments has a fractionation rate determining the proportion of its contents released to the decomposition compartments in a time step. For the compartment of non-woody litter, this rate is equal to 1 which means that all of its contents is released in one time step, whereas for the woody litter compartments this rate is smaller than 1. Litter is distributed over the decomposition compartments of extractives, celluloses and lignin-like compounds according to its chemical composition. Each decomposition compartment has a specific decomposition rate, determining the proportional loss of its contents in a time step. Fractions of the losses from the decomposition compartments are transferred into the subsequent decomposition compartments having slower decomposition rates while the rest is removed from the system. The fractionation rates of woody litter and the decomposition rates are controlled by temperature and water availability.

Figure 2.2. Flow chart of the soil model. The boxes represent carbon compartments, and the arrows represent carbon fluxes.

The dynamics of carbon in the litter (Equation 13 to 15) and the decomposition compartments (Equation 16 to 20) can be described as follows:

$$\frac{dx_{nwl}}{dt} = u_{nwl} - a_{nwl} x_{nfwl} \tag{14}$$

$$\frac{dx_{fwl}}{dt} = u_{fwl} - a_{fwl} x_{fwl} , \tag{15}$$

$$\frac{dx_{cwl}}{dt} = u_{cwl} - a_{cwl} x_{cwl} , \tag{16}$$

$$\frac{dx_{ext}}{dt} = c_{nwl\_ext} a_{nwl} x_{nwl} + c_{fwl\_ext} a_{fwl} x_{fwl} + c_{cwl\_ext} a_{cwl} x_{cwl} - k_{ext} x_{ext} , \tag{17}$$

$$\frac{dx_{cel}}{dt} = c_{nwl\_cel} a_{nwl} x_{nwl} + c_{fwl\_cel} a_{fwl} x_{fwl} + c_{cwl\_cel} a_{cwl} x_{cwl} - k_{cel} x_{cel} , \tag{18}$$

$$\frac{dx_{lig}}{dt} = c_{nwl\_lig}\,a_{nwl}\,x_{nwl} + c_{fwl\_lig}\,a_{fwl}\,x_{fwl} + c_{cwl\_lig}\,a_{cwl}\,x_{cwl} +$$
$$+ p_{ext}\,k_{ext}\,x_{ext} + p_{cel}\,k_{cel}\,x_{cel} - k_{lig}\,x_{lig} \tag{19}$$

$$\frac{dx_{hum1}}{dt} = p_{lig}\,k_{lig}\,x_{lig} - k_{hum1}\,x_{hum1}\,, \text{ and} \tag{20}$$

$$\frac{dx_{hum2}}{dt} = p_{hum1}\,k_{hum1}\,x_{hum1} - k_{hum2}\,x_{hum2}\,. \tag{21}$$

where:
- $u_i(t)$ the input of litter type i to the system (i = non-woody litter (nwl), fine woody litter (fwl) or coarse woody litter (cwl)),
- xi(t) the weight of organic carbon in woody litter compartment i at time t (i = fine or coarse woody litter),
- ai the rate of invasion of litter i by microbes,
- $x_j(t)$ the weight of organic carbon in each decomposition compartment j at time t (j = extractives (ext), celluloses (cel), lignin-like compounds (lig), simple humus (hum1) or complicated humus (hum2)),
- cij the concentration of compound group j in litter type i,
- kj the decomposition rate of compartment j, and
- p_i the proportion of mass decomposed in compartment i transferred to a subsequent compartment.

The invasion rates of litter by microbes (ai) and the decomposition rates (kj) depend on effective temperature sum (T, effective temperature sum, 0 °C threshold) and summer drought (D, precipitation minus potential evapotranspiration from May to September) as follows

$$k_i\,(T,D) = k_{i0}\,\big(1 + s * 0.000387(T - 1903) + 0.00325\,(D - (-32))\big) \tag{22}$$

$$a_i\,(T,D) = a_{i0}\,(1 + s * 0.000387(T - 1903) + 0.00325\,(D - (-32))) \tag{23}$$

where a_{i0} and k_{i0} denote microbial invasion and decomposition rates in chosen standard conditions (T = 1903 °C days, D = -32 mm). For the humus compartments, parameter s may have a value lower than one to reduce the temperature sensitivity of humus decomposition; for the other decomposition rates, s is equal to one.

The decreasing effect of summer drought on decomposition was included in the model to account for slow decomposition observed in Mediterranean-like climate where summers are dry (Liski et al., 2003a). In similar conditions in the southern hemisphere, the months from May to September should be replaced by another period of five months during which drought is experienced. In the wet tropics, this term is not important, because decomposition is fast in any case because of high

temperatures. If the user assumes no drought effects on decomposition, he/she should use a precipitation deficit value equal to 0 mm in the model. The model has so far been validated in the northern hemisphere only.

Summer drought (D) is calculated as summer precipitation minus potential evapotranspiration (PET). The soil carbon module was calibrated using PET values calculated using the Priestley-Taylor equation and the algorithms of the BIOM model (Sykes et al., 1996). For the CO2FIX users, a simple spreadsheet program was made that calculates the PET according to the Thorthwaite method. According to tests carried out, this will only cause minor differences in the results.

2.3.3 Parameter values

Parameter values have been determined for the chosen standard conditions prevailing in southern Finland and middle Sweden (T = 1903 °C days, D = -32 mm) (Table 2.1). Equation 21 and 22 are used to modify these values to the parameter values for other conditions.

Different kind of data have been used to determine the parameter values. The decomposition rates of the extractives, the celluloses and the lignin-like compounds and the transfer fractions of decomposed matter between the compartments are based on data from litter bag experiments (Berg et al., 1991). Decomposition rates of humus are based on data on soil carbon accumulation on a 5500 year soil chronosequence (Liski et al., 1998). The invasion rates of woody litter by microbes are based on data on decay of logs (Tarasov and Birdsey, 2001). The climatic dependencies (Equation 21 and 22) were determined based on data from Berg et al. (1993). The tolerance of humus decomposition on temperature is based on soil carbon measurements along a temperature gradient (Liski et al., 1999).

Table 2.1. Parameter values of the model and their estimated uncertainties under chosen standard conditions (annual mean temperature 3.3 °C, effective temperature sum (0 °C threshold) 1903 °C days and precipitation minus potential evapotranspiration from May to September -32 mm).

Parameter	Value	Notes
Invasion rates of woody litter by microbes (year^{-1})		
Non-woody litter (a_{nwl})	1	
Fine woody litter (a_{fwl})	0.54	
Coarse woody litter (a_{cwl})	0.030 or 0.077	Smaller value for larger logs (Ø 20 - 60 cm), larger value for smaller logs (Ø 5 - 20 cm)
Decomposition rates (year^{-1})		
Extractives (k_{ext})	0.48 or 0.82	Smaller value for conifers, larger value for deciduous plants
Celluloses (k_{cel})	0.30	
Lignin-like compounds (k_{lig})	0.22	
Faster humus (k_{hum1})	0.012	
Slower humus (k_{hum2})	0.0012	
Formation of more complex compounds in decomposition (proportion of decomposed mass)		
Extractives to lignin-like compounds (p_{ext})	0.2	
Celluloses to lignin-like compounds (p_{cel})	0.2	
Lignin-like compounds to faster humus (p_{lig})	0.2	
Faster humus to slower humus (p_{hum1})	0.2	

The initial contents of the compartments of the soil module can be determined in two ways; 1) manually, just like any other input information, or 2) allowing CO2FIX to calculate equilibrium contents based on litter input. Among the cohort parameters, the user needs to give information on chemical litter quality. The concentrations of the three fractions can be measured using common laboratory methods (McClaugherty et al., 1985), and for many species reference values are available in literature (Hakkila, 1989; McClaugherty et al., 1985; Trofymow et al., 1995). The standard value of the temperature sensitivity for humus decomposition (s) is 0.6. The initial decomposition rate for soluble compounds (k0sol) is equal to 0.5 year^{-1} for the litter of conifers and equal to 0.8 year^{-1} for the litter of deciduous trees.

2.4   Products module

The products module tracks the carbon after harvesting. In the same year as the harvest takes place, several intermediate processing and allocation steps are done, until the carbon resides in the end products, the millsite dump, or is transferred to the bioenergy module (Figure 2.3). When end products are discarded at the end of their lifespan, they can be recycled, deposited in a landfill, or they can be used for bioenergy, which is taken care of in the bioenergy module. Carbon is released to the atmosphere through decomposition at the millsite dump, at the landfill, or via the bioenergy module. The products module is based on a model developed and used before by Karjalainen et al. (1994) for modelling the carbon budget for the Finnish

forest sector. A more detailed version has been applied for the European forest sector (Karjalainen et al., 2002; Eggers, 2002).
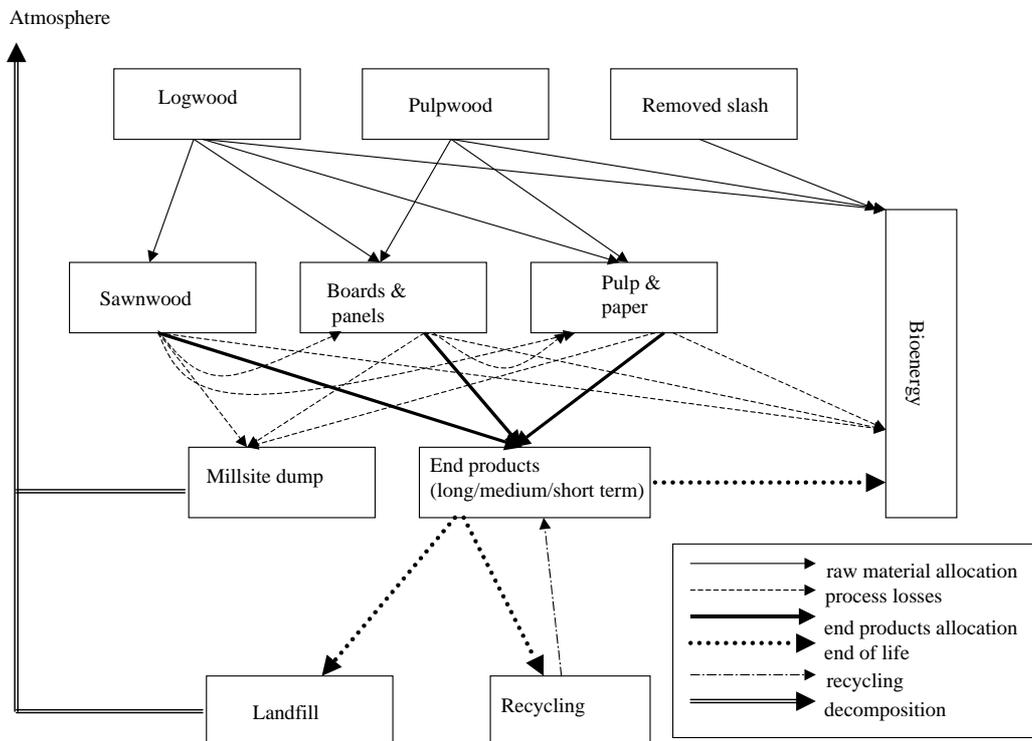
Figure 2.3. Outline of the wood products module. Boxes are stocks of carbon, the arrows show transfers of carbon between different phases of the chain (from harvest to final allocation). The distinction between logwood, pulpwood and slash is done in the biomass module.

Stem and harvested branch biomass are the inputs to the products module. Within the products module only carbon is tracked that has its origin in the biomass part, so carbon added in the processing stages (for instance glue) are not taken into account. Harvested biomass of stems and branches is separated into logwood and pulpwood. Slash can optionally be used to produce bioenergy, see for details section 2.5.

In the first step, logwood is allocated to the commodities sawn wood, boards & panels and pulp & paper, and pulpwood is allocated to boards & panels and pulp & paper. Processing losses are transferred to the bioenergy module.

The products module distinguishes three categories of end products: long term, medium term and short term products. Each of the commodities (sawn wood, boards & panels and pulp & paper) is distributed over these end product categories. Process losses can either be re-used in 'lower grade' production lines, can be used as bioenergy, or can be dumped at the mill site.

For each end product category, for the mill site dump and for the landfill, an a half live is defined. In CO2FIX V 3.1 exponential discard or decay functions are used:

$$P_{t+1,k} = P_{tk} * (1 - \ln(2) / L_k) \tag{24}$$

where
P_{tk} is the amount of carbon in product category 'k' at time 't' and
L_k is the half live for category 'k'

When this function is applied, the average carbon stock remaining in a certain end product compartment amounts to 50% of the original amount after a period equal to the half live. This is illustrated for different half lives in Figure 2.4.
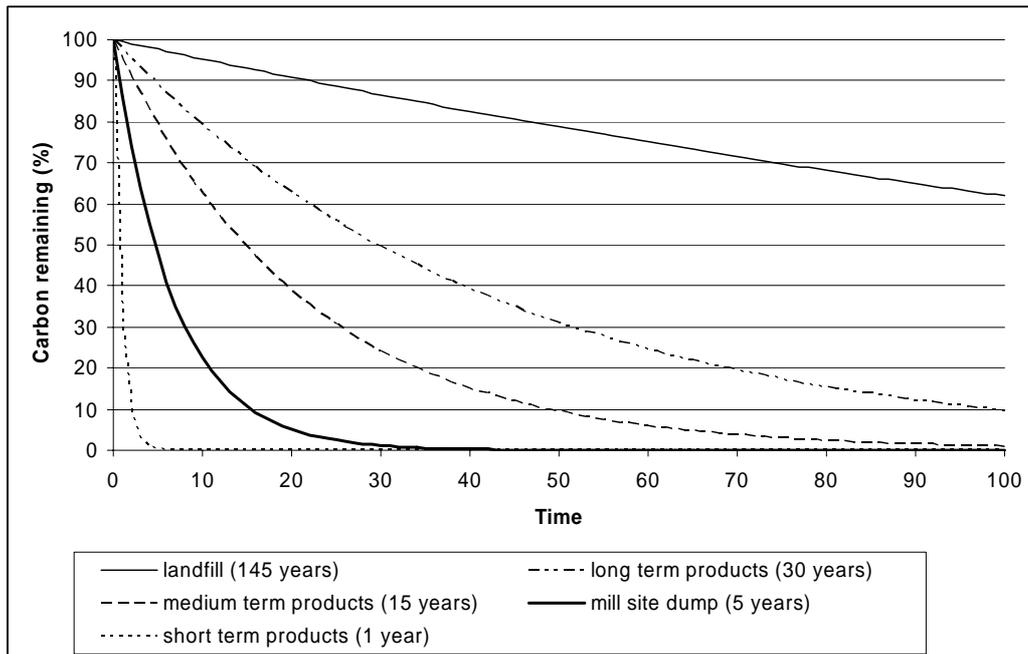
Figure 2.4. Discarding curves of carbon in end use products, mill site dump and landfill for their default 'half lives'.

When end products are discarded, they can be recycled, deposited in a landfill, or they can be used for bioenergy. The latter is taken care of in the bioenergy module. A product can only be recycled to the same life-span category or lower. From the landfill and the mill site dump carbon is released directly to the atmosphere.

Two default parameter sets are delivered with the model, a set with high processing and recycling efficiency and a set with low processing and recycling efficiency. Their values are included in Annex 5.

2.5 Bioenergy module

2.5.1 Background

Bioenergy is energy derived from biomass. Biomass may be produced from the so-called energy crops (such as sugarcane) or forests, or as a byproduct of forestry, sawmilling and agriculture. Biomass can be utilized directly for heat energy or can be converted into gas, electricity or liquid fuels.

Energy production from fossil fuels has very different implications than energy production from biomass, regarding CO_2 emissions. Burning fossil fuels releases CO_2 that has been locked up for millions of years. By contrast, burning biomass simply returns to the atmosphere the CO_2 that was absorbed as the plants grew and there is no net release of CO_2 if the cycle of growth and harvest is sustained (see Figure 2.5). In other words, sustainably produced biomass is CO_2 neutral. However, if a forest area is harvested and not replanted, or is permanently lost due to natural events like fire or disease, then the CO_2 emitted by bio-energy is not captured again and the CO_2 emissions associated to the bioenergy option should be accounted for.
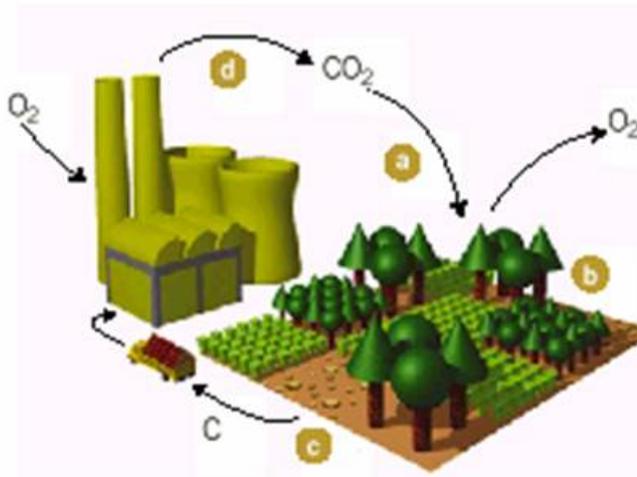
Figure 2.5. Carbon cycle of a bioenergy power plant (Source: IEA Bioenergy, 2001).

Substituting sustainably produced bioenergy for fossil fuels is a way of mitigating greenhouse gas emissions to the atmosphere. In contrast with carbon storage within the forest, the carbon benefits provided by bioenergy substituting for fossil fuels are irreversible, even if the bioenergy scheme only operates for a fixed period. Within the CO2FIX model, two types of biomass fuel are considered: one resulting from industrial residues (such as discarded products, losses during processing) and one from slash that is removed from the forest site. For both processes, different baseline and substituting technologies and fuels can be specified.

2.5.2 Calculation of GHG mitigation

There are two general ways of mitigating carbon emissions by using bioenergy: a) Substituting fossil fuels by biomass, and b) Improving the characteristics of the existing biomass technologies –e.g. by replacing an old technology by a newer more efficient one.

The specific mitigation to be attained by a given bioenergy option per unit area depends on the following parameters:
- Amount of biofuels produced annually
- Energy content of the biofuels and fossil fuels
- Efficiency of the bioenergy and fossil fuel technology
- Emission factors of the current and alternative fuel/technology

The production of energy from biomass releases greenhouse gases (GHG) other than CO_2, which are not absorbed with plant re-growth. Such gases are methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO) and non-methanogenic organic compounds (TNMOC). A proper mitigation analysis needs to account for the difference in emissions of non-CO_2 GHG between the proposed biomass technology and the (fossil) fuel to be substituted. For each GHG we estimate the difference between the emissions from the old and the new technology for producing the same amount of energy:

$$\text{GHGmit}_j = E_{sj} - E_{aj} \qquad \text{(Mg gas yr}^{-1}\text{)} \qquad (25)$$

where
GHGmit_j is greenhouse gas mitigation of greenhouse gas 'j'
E_{sj} is emissions of greenhouse gas 'j' of the fuel/technology to be substituted
E_{aj} is emissions of greenhouse gas 'j' of the alternative technology

The emissions of the alternative technology can be calculated according to:

$$E_{aj} = FI * \text{€}_{aj} \qquad \text{(Mg gas yr}^{-1}\text{)} \qquad (26)$$

where:
FI is fuel input (Mg DM yr^{-1})
€_{aj} is emission factor for the alternative technology for each greenhouse gas 'j', in Mg gas/ Mg fuel

The equivalent emission of fossil fuels (or the technology to be replaced) is calculated according to:

$$E_{sj} = FI * (EC_a/EC_s) (\eta_a/\eta_s) * \text{€}_{sj} \quad \text{(Mg gas yr}^{-1}\text{)} \qquad (27)$$

where:

EC_a is energy content of the alternative (bioenergy) fuel
EC_s is energy content of the fuel to be substituted
η_a is energy efficiency of the alternative technology
η_s is energy efficiency of the technology to be substituted
$€_{sj}$ is emission factor of the fuel/technology to be substituted for each GHG 'j'

In order to get the compound effect of all greenhouse gases, emissions of each gas have to be weighed by their respective global warming potential. Therefore, the total mitigation of GHG emissions will be:

$$TOTGHGmit = \Sigma \ (GHGmit_j * GWP_j) \quad \text{(in Mg C equiv)} \quad (28)$$

where:

$GHGmit_j$ is the mitigation associated to each GHG 'j', and
GWP_j is the global warming potential of each GHG 'j'

In the CO2FIX model CO_2 emissions from bioenergy technologies should always be kept at zero. The reason for this is that in case of a sustainable harvesting cycle, net emissions are zero. In case of a non-sustainable harvest (not followed by re-growth), the net emissions will show up as a reduction of carbon stocks at the forest level. The substitution of fossil fuels by biomass leads to a permanent GHG mitigation. Therefore, we can regard the cumulative mitigated GHG as an increasing carbon stock in the forests.

2.6 Forest financial module

Financial costs and benefits are assessed in CO2FIX V 3.1 with a simple module. Different types of cost and benefit inputs have to be specified by the user. CO2FIX calculates the discounted costs and income, as well as the Net Present Value (NPV) per carbon credit, since income from carbon credits is not asked as an input. If the result of the case is a negative NPV, this can be seen as the costs per credit. The calculation of the net costs and income balance in a year is the sum of all costs made and benefits earned in that year. The discounted balance (B) of a year is the balance multiplied with a financial discount factor ($D_{F,t}$),

$$CB_{t,discounted} = CB_t \cdot D_{F,t} \quad (29)$$

where $D_{F,t}$ is calculated with:

$$D_{F,t} = \frac{1}{1+r_{F,1}} \cdot \frac{1}{1+r_{F,2}} \cdot \ldots \cdot \frac{1}{1+r_{F,t}} = \frac{D_{F,t-1}}{1+r_{F,t}} \quad (30)$$

in which $r_{F,t}$ is the financial discount rate specified for year t. The discount rate (r) is not considered constant, but can be specified for several years, allowing a trend in discounting the costs.

The net present value (NPV) of a forest in a given year t is obtained through summing the total amount of discounted costs and benefits from the beginning of the project up to that year:

$$NPV_t = \sum_{tb}^{t} CB_{t,discounted} \tag{31}$$

2.7   Carbon accounting module

2.7.1   Introduction

In the past, many methods have been developed and proposed to calculate carbon credits. At the CoP9 meeting in December 2003, the exact carbon crediting methods for CDM afforestation or reforestation (CDM-AR) projects were settled, as well as the eligible carbon pools (Decision, 19/CP.9 on 'Modalities and procedures for afforestation and reforestation project activities under the clean development mechanism in the first commitment period of the Kyoto Protocol' (FCCC/CP/2003/6/Add.2), see for the exact text http://unfccc.int/resource/docs/cop9/06a02.pdf). The official methods are temporary credits (tCERs) and long term credits (lCERs). For projects other than CDM-AR projects, no official credits can be obtained yet. For such projects, the stock change method is recommended. However, there are no official accounting rules for this type of method yet.

The user (project owner) can specify during which period credits can be sold. This period does not necessarily have to start at the same time as the project starts. The first verification has to be carried out within five years after the start of the crediting period, next verifications will take place every 5 years. The crediting period can be 20 or 30 years, and can be extended once in the case of a period of 30 years, and extended twice in case of a period of 20 years, leading to a maximum crediting period of 60 years.

Within CO2FIX, the stock change method, temporary credits and long term credits with and without reversal can be calculated. Since carbon credits need to be compatible with avoided emissions, they are expressed in CO2-equivalents (CO_2e). For this purpose, all carbon pools that are taken into account are converted to CO2-equivalents by multiplying them with a factor 44/12, their respective molecular weights. However, the user must be aware that within the CO2FIX carbon accounting module, leakage and greenhouse gas emissions other than CO_2 are not taken into account.

2.7.2 Stock change approach

The stock change method is a simple and clear way of calculating the amount of sequestered carbon. In its most simple way, it calculates the difference between the amount of carbon stored in year t minus the amount stored in year (t-1). In formula:

$$C_{seq,t} = C_t - C_{t-1} \qquad (32)$$

where $C_{seq,t}$ is the sequestered amount of carbon at year t, and C_t is the amount of carbon stored at year t. In real life projects, credits will be issued within a certain crediting period. The amount of credits that can be obtained then becomes the difference between the starting year of that period (or base year, tb) and the last year of that period (or crediting year, tc). In formula:

$$C_{seq,tc} = C_{tc} - C_{tb} \qquad (33)$$

In case a baseline is applied, the amount of carbon sequestered according to this baseline has to be subtracted as well (Figure 2.6).
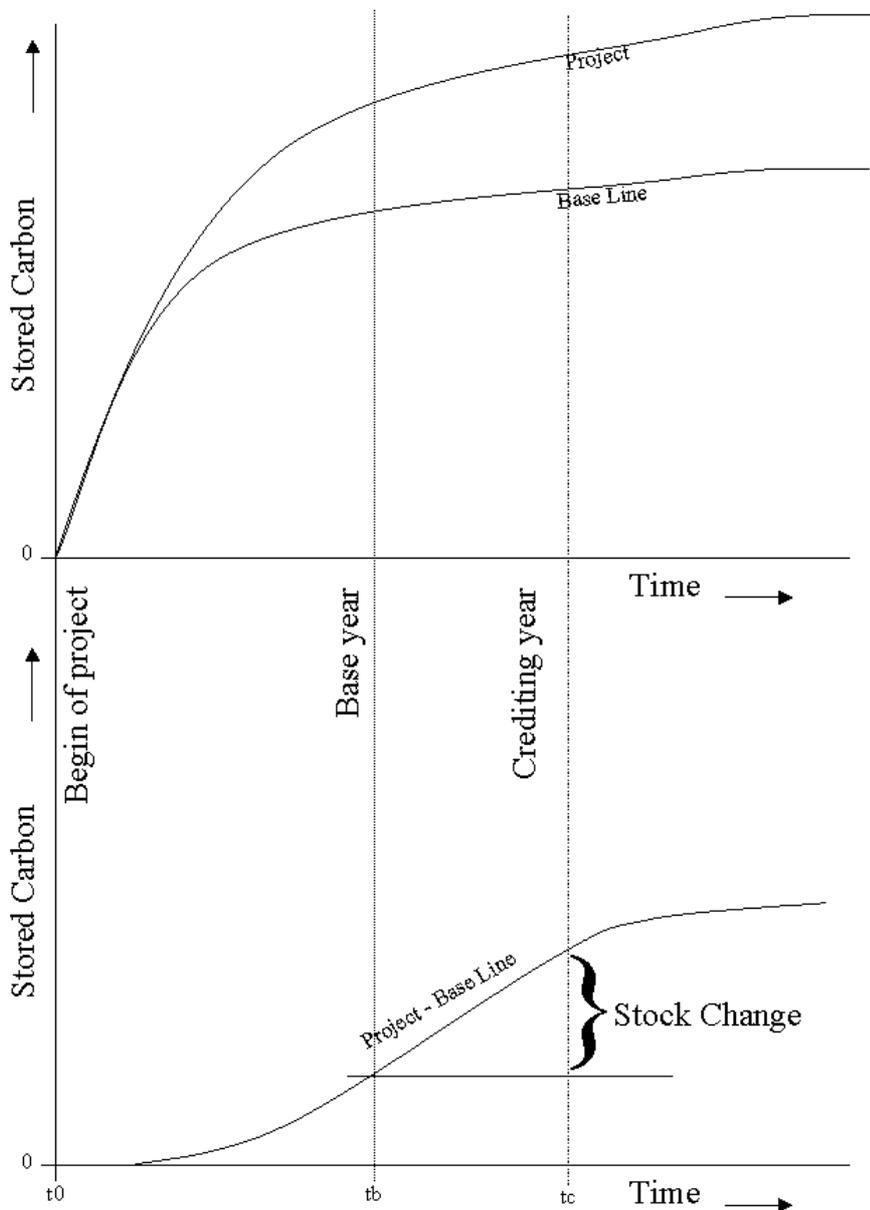
Figure 2.6: A visual example of carbon stocks in a CDM AR project and baseline, the difference between the two, and the calculation of the amount of credits according to the stock change approach.

2.7.3 Temporary crediting approach

A temporary CER or tCER is a certified emission reduction (CER = 1 Mg of CO_2e) issued for an afforestation or reforestation project activity under the CDM which expires at the end of the commitment period following the one during which it was issued. The amount of credits that can be earned during a verification is equal to the

amount of sequestered carbon at that moment, taking into account the baseline scenario:

$$nPG_t = (MnC_t - BnC_t) * 44/12 \qquad (34)$$
$$tCER_t = nAG_t \qquad (35)$$

where:

nPGt   is the net Project greenhouse gas removal by sinks at time t (in CO_2e, but without taking into account non-CO2 greenhouse gasses and leakage)

MnCt   is the Mitigation net CO_2 removal by sinks at time t (carbon stock of the mitigation scenario)

BnCt   is the Baseline net CO_2 removal by sinks at time t (carbon stock of the baseline scenario)

2.7.4 Long term crediting approach

A long-term CER or lCER is a certified emission reduction (CER) issued for an afforestation or reforestation project activity under the CDM, which expires at the end of the crediting period of the afforestation or reforestation project activity under the CDM for which it was issued. Since lCERs are valid for a long period, there is a risk that the sequestered carbon will be lost later in time. In that case, the lCERs can either be reversed (lCERs with reversal), or the project owner can choose not to sell these credits (lCERs without reversal). In case of lCERs with reversal, the lCERs are calculated as following:

$$lCER_t^a = tCER_t - \sum_{i=c0}^{t-5} lCER_i^a \qquad (36)$$

In case of lCERs without reversal, expected future carbon losses are taken into account already beforehand. In order to do this, we must check if the net sequestered carbon at any verification point in future will be lower than the current amount.

$$\text{If } nPG_t > \min(nPG_{[cp-t]}) \Rightarrow lCER_t^b = \min(nPG_{[cp-1]}) - \sum_{i=c0}^{t-5} lCER_i^b \qquad (37)$$

$$\text{If } nPG_t \leq \min(nPG_{[cp-t]}) \Rightarrow lCER_t^b = tCER_t - \sum_{i=c0}^{t-5} lCER_i^b \qquad (38)$$

For a visualisation of these approaches, see Section 3.10.

2.7.5 Kyoto assist tree

Under the Kyoto Protocol, several types of projects are eligible, each with its specific requirements. In order to help the user to determine the type of project, a decision tree has been constructed. By answering the questions, the user will be guided through the tree, leading to the type of his project. The outline of this decision tree is shown in Annex 7.

3 How to use the model

3.1 Introduction

This chapter shows the model implementation in C++ with a user-friendly interface. We explain how the model can be obtained and operated. The text in this chapter was originally written for the manual, and therefore the text overlaps with the text in Chapter 2. For the users that want a quick start, we refer to the separate manual (delivered with the model as pdf file).

3.2 How to obtain the model

The software can be found on the World Wide Web on the site: http://www.efi.fi/projects/casfor/. Go to 'CO2FIX-model V 3.1' and after reading the disclaimer and completely filling out the registration form (including your email address) click 'I agree'. A response email is automatically sent to you instantly. It gives the URL where you can download the software. Go to that URL and start the download (CO2FIX V 3.1 installer.exe) to a local directory (e.g. C:\temp).

The purpose of the registration is to have insight to the user group of CO2FIX. The information you have provided will be used only for internal use and will not be given to any third party. With your e-mail address (which is obligatory in order to receive CO2FIX) it is possible for us to keep you informed on major changes and/or additions to CO2FIX. We will use that only in seldom cases through a mailing list address. Your personal email address is thereby secured.

Execute the 'CO2FIX V 3.1 installer.exe' and follow instructions in the install shield. Successful installation will result (amongst others) in a CO2FIX executable, a subdirectory called 'Samples' with the case studies and a subdirectory called 'Special cases' with examples for some special cases.

3.3 Main menu and General parameters

To start double click the CO2FIX icon. The first step consists of the creation of a new case study, or of opening an already existing one. When a case study is opened, all menu options and icons will be active (Figure 3.1).

Figure 3.1. Main menu options and icons.

From left to right the icons show (alternatively the drop down menus 'File', 'Edit', etc can be used as well):
- Six standard windows icons;
- Seven icons for the seven main menus for parameterisation (general parameters, biomass module, soil module, products module, carbon accounting module, and financial module);
- 'New window' icon that allows you to open multiple case studies at the same time;
- Six icons to view output in different ways;
- 'About' icon.

Within this manual, we will mostly follow the Pine-Oak case study to illustrate the various in- and output options. This is an example of an unevenaged mixed stand of Pine (Pinus spp.) and Oak (Quercus spp.), characteristic of the highlands of Central Mexico.

When you click on the **General parameters** icon, a dialogue screen will appear, containing four tabs: ***Comments, Scenario, General Parameters***, and ***Cohorts***. In the ***Comments*** tab, any written information can be specified, such as origin of data, location of case study, etcetera. The Scenario tab is a new feature in V 3.1 and allows the definition of different scenarios for the same case study. This is explained further in the chapter on carbon accounting. The ***General Parameters*** tab allows for inserting main input data to describe the case study, and the simulation methods chosen (see also the chapter on the biomass module). In the ***Cohorts*** tab, the name and type of the cohorts to be simulated can be specified, see also the chapter on the biomass module.

In many input screens, data is entered in the form of a table. Usually the data entered in these tables will be visualised in a graph next to the table. During simulations, CO2FIX will make linear interpolations in between the data points. If the maximum value is exceeded, the value of the last data point will be used.

3.4 Biomass module

3.4.1 The cohort approach

The biomass module of the CO2FIX model is a flexible tool that can be applied to a wide variety of forest types. Besides the regular monospecies plantations, it is possible to model multi-species and uneven aged stands. The model used here is a 'cohort model' (Reed, 1980), where each cohort is defined as a group of individual trees or as a group of species, which are assumed to exhibit similar growth, and which may be treated as single entities within the model (Vanclay, 1989; Alder and Silva, 2000). Each cohort has growth, mortality, and turnover and can be harvested. Further, interaction between cohorts can be defined (Figure 3.2).
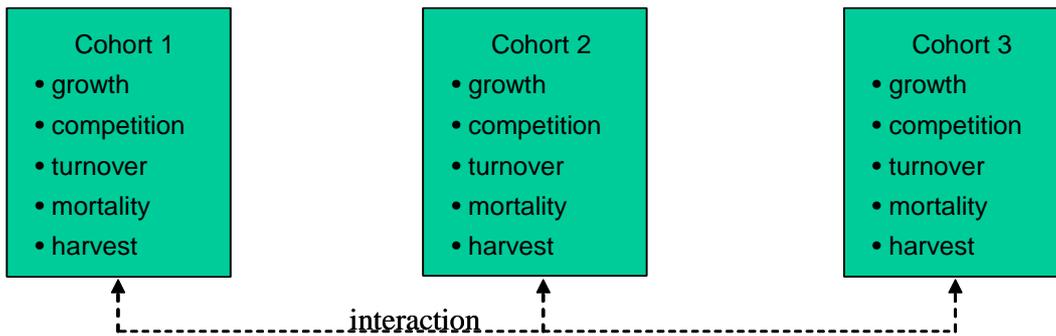
Figure 3.2. Processes within and interaction between cohorts.

Cohorts can be defined in the **General Parameters** main menu, tab **Cohorts**. The Cohorts screen allows defining per scenario the number of cohorts that form the stand, the starting age of each cohort, and whether it is a coniferous or broadleaved species (Figure 3.3). This latter information is used to characterise the quality of the litter input to the soil module.
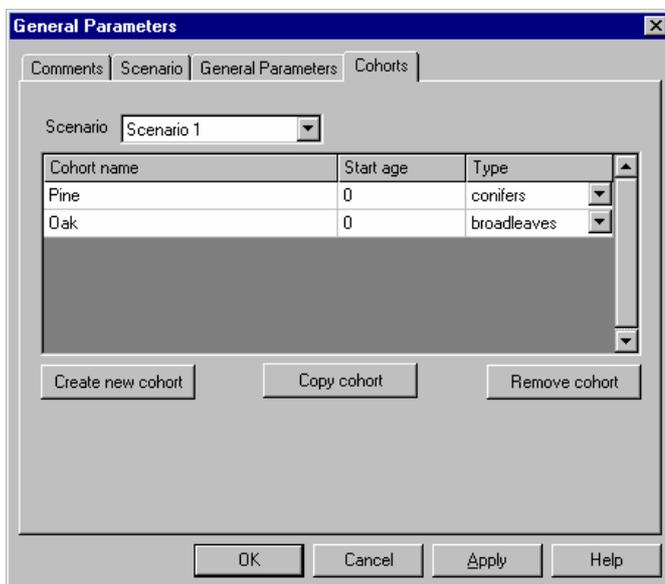
Figure 3.3. **Cohorts** *screen in main menu* **General Parameters***.*

3.4.2 Stemwood growth

The driving factor of each cohort in the biomass module is the stemwood production in volume per ha (Figure 3.4), as this is the information that is usually readily available for most forest types. Multiplication with the stemwood density and the carbon content yields carbon flux into the stemwood compartment. Fluxes into the other biomass compartments (roots, branches, foliage) are determined by their growth, relative to the stemwood production, and their respective carbon contents. Turnover of all biomass compartments is added to the soil, as well as any slash that will arise due to management activities. Harvested stemwood is tracked further in the products module.
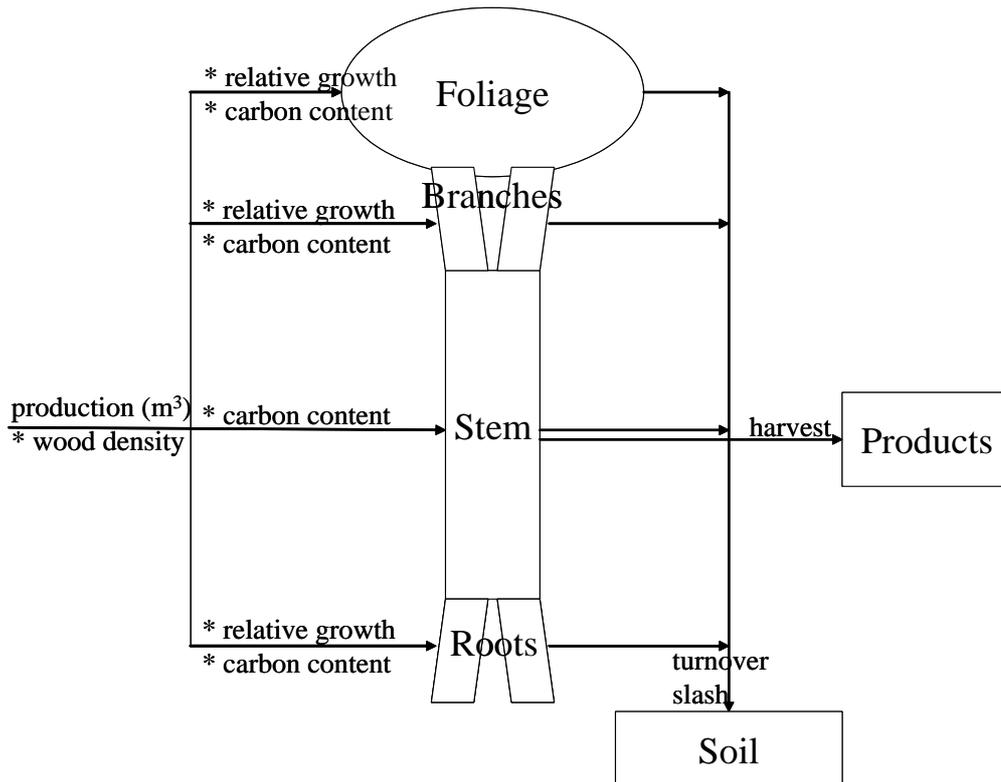
Figure 3.4. Schematic representation of processes and flows in the biomass module for one cohort.

CO2FIX V 3.1 allows two basic approaches for modelling growth of the cohorts:
tree growth as a function of tree or stand age, and
tree growth as a function of biomass.

Re 1. In a situation where the age of the forest and/or trees is known the growth of tree biomass is often expressed as a function of time. In case of stemwood volume, this is called current annual increment (CAI, Figure 3.5a). When natural mortality is taken into account separately, this should be gross annual increment. Stemwood increment data are most commonly available, usually in the form of yield tables.

Re 2. In a situation, where the tree/forest age is not known (e.g. the case of tropical primary or secondary forests), another approach is needed. A common method in such a situation is to express growth as a function of the ratio between actual biomass and maximum attainable biomass (Figure 3.5b).
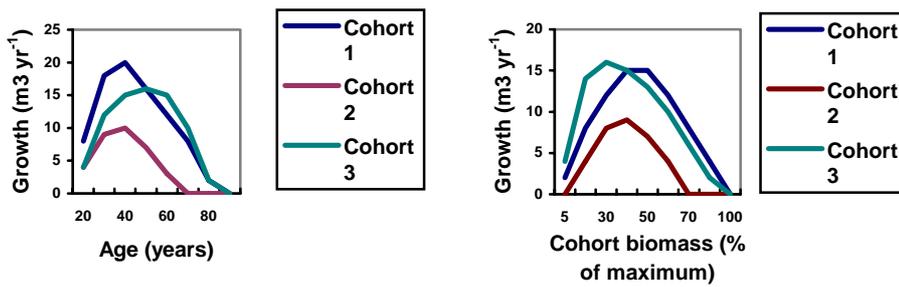
Figure 3.5a. Current annual volume increment (CAI) of three cohorts in a forest stand as a function of cohort age. (Exemplary only; growth will normally not decline to 0)
Figure 3.5b. Current annual increment (CAI) (m^3 ha^{-1} yr^{-1}) of three cohorts in a forest stand as a function of cohort biomass. (Exemplary only; growth will normally not decline to 0)

The growth method to be applied in the simulation can be chosen in the **General Parameters** main menu, tab **General Parameters** (Figure 3.6). The growth method chosen will be applied to all cohorts and all scenarios within the simulation. If growth as a function of aboveground biomass is chosen, the box Maximum biomass in the stand should be filled in as well. As a guidance to maximum biomass data, Table 3.1 is provided. Other options in this tab are the choice of competition method, the way management mortality is included and how long the simulation should run. The options on competition and management mortality are explained later on in this chapter.
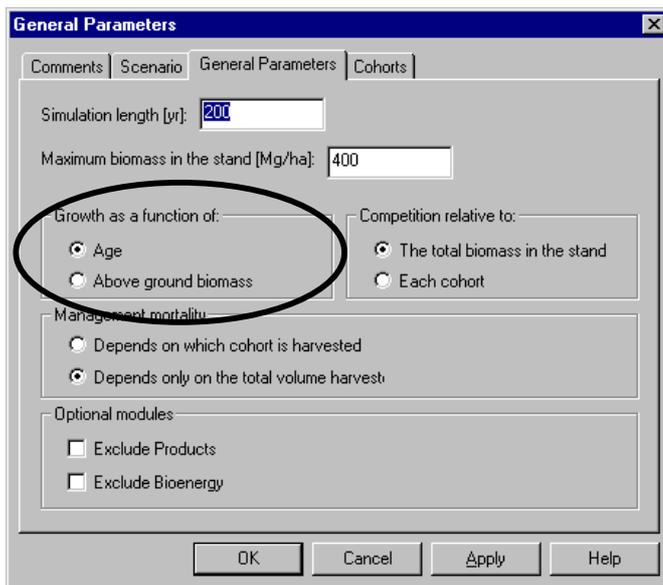
*Figure 3.6. **General Parameters** screen, in main menu **General Parameters**, with in this case growth as a function of age.*

Table 3.1. Current average standing biomass (tonnes dry matter per ha) in different biomes of the world (Watson et al., 2000)

Biome	Current average dry matter content
tropical forests	241
temperate forests	113
boreal forests	128
tropical savannas	59
temperate grasslands	14
deserts	4
tundra	13
wetlands	86
croplands	4

The parameterisation of the stem compartment is done in the **Biomass** main menu, tab ***Stems***. Figure 3.7 gives an example of the parameterisation of the ***Stems*** compartment, in case of the age related growth method. In this case, stem volume increment is given with 5-year intervals. In addition to the volume increment, the carbon content of dry matter, the basic wood density (dry matter per fresh volume), and any carbon initially present on the site need to be given. The latter is mainly the case when simulations do not start at age zero. These data need to be filled in for each cohort in each scenario. Information on biomass of many forests around the world can be found for example in Cannell et al. (1982). The maximum aboveground biomass of the stand – or of each of the cohorts – can be estimated from inventory data coming from undisturbed or lightly disturbed forests in or around the site area. Locally developed or published regression equations that convert inventory data to standing biomass should be used for this purpose (Brown, 1997). If only commercial volume data are available for the whole forest or the cohorts, standardized biomass expansion factors can be applied to these data. If no inventory or volume data are available, published data of forests under similar ecological conditions should be consulted. Brown (1997) gives an overview on biomass estimation in the tropics, including many tables with biomass data. It also includes a long annex with wood densities for tropical species. Further the Global Forest Resource Assessment (FAO, 2001) is a valuable source of information on biomass parameters. Age-dependent increment can be found in yield tables. Yield tables are usually available for most species that are planted in commercial plantations. An overview of European yield tables can be found at http://www.efi.fi/projects/forsce/yield_tables.html.
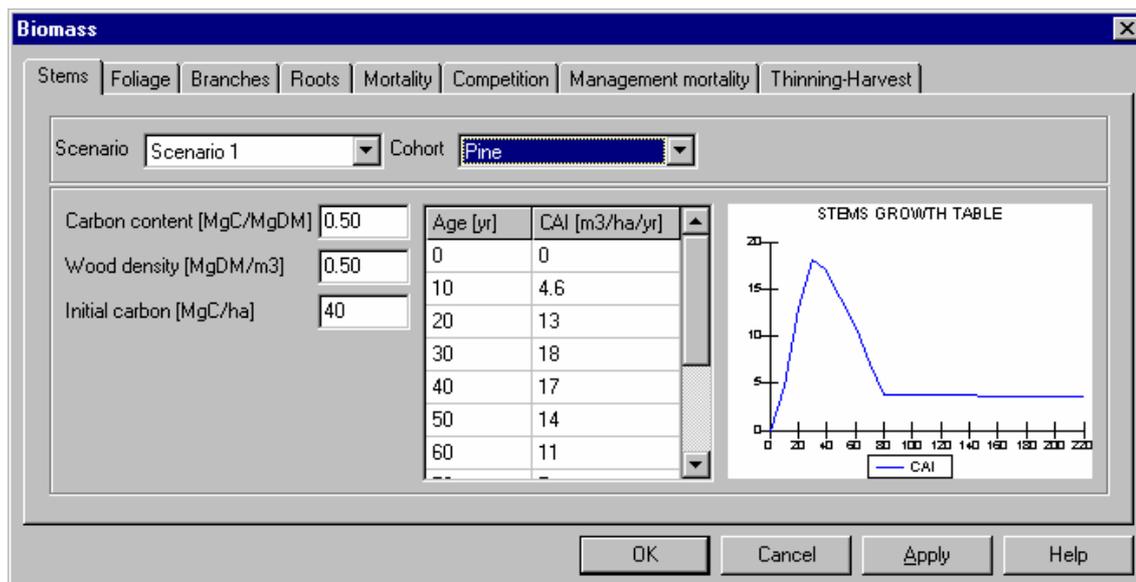
Figure 3.7. **Stems** *parameterisation screen in main menu* **Biomass**.

3.4.3 Biomass growth and turnover of foliage, branches, and roots

The biomass growth of foliage, branches and roots are expressed as fractions, relative to the growth rate of the stem biomass. These fractions are additional to the stem biomass production. Relative fractions can change with age or with the ratio actual biomass over maximum biomass, depending on the growth method in question (Figure 3.8).

$$B_i = F_i * B_s$$

where:
F_i is relative biomass allocation coefficient (F_f for foliage, F_b for branches, F_r for roots)

B_i is growth of biomass (B_f for foliage, B_b for branches, B_r for roots)

B_s is growth of stem biomass
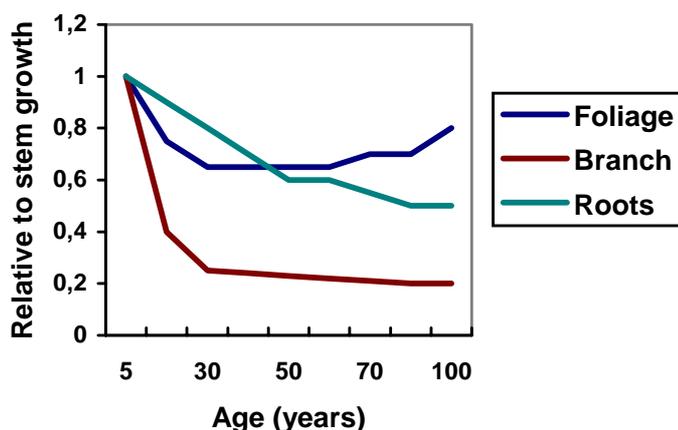
Figure 3.8. Example of the growth of biomass of foliage, branches and roots relative to stem biomass growth (biomass allocation coefficient) as a function of age.

Turnover is the annual rate of mortality of the biomass component in question (foliage, branches, roots). A turnover rate of 0.3 means that 30% of the total biomass of the component is converted to litter every year. The stems compartment has no separate turnover rate. Turnover of stems is parameterised by the mortality process (see next section).

For each of the three compartments **Foliage, Branches** and **Roots**, a separate tab is present in the **Biomass** menu. For each cohort in each scenario the allocation to these compartments needs to be given, relative to the stems dry matter growth rate. Figure 3.9 gives an example for the **Branches** compartment, with the growth rate depending on age. Again, data entered in the table will be visualised in the graph. The curve in Figure 3.9 has a typical shape. Very often in young trees most of the NPP is allocated to foliage, branches and roots. When the annual volume increment increases, the relative allocation to other compartments decreases. When the trees mature and the annual increment decreases, relative allocation to other compartments increases again, in order to keep the absolute production of for instance foliage constant. Together with turnover rates of these compartments, the stocks of carbon in the foliage, branches and roots are simulated. Note that when you click 'Apply' or 'OK' the simulation is immediately updated. The growth correction factor makes it possible to apply a defined case study to a site of different fertility where allocation to roots and foliage may be higher. In that case it is avoided that the parameterisation of the complete case study needs to be done again.
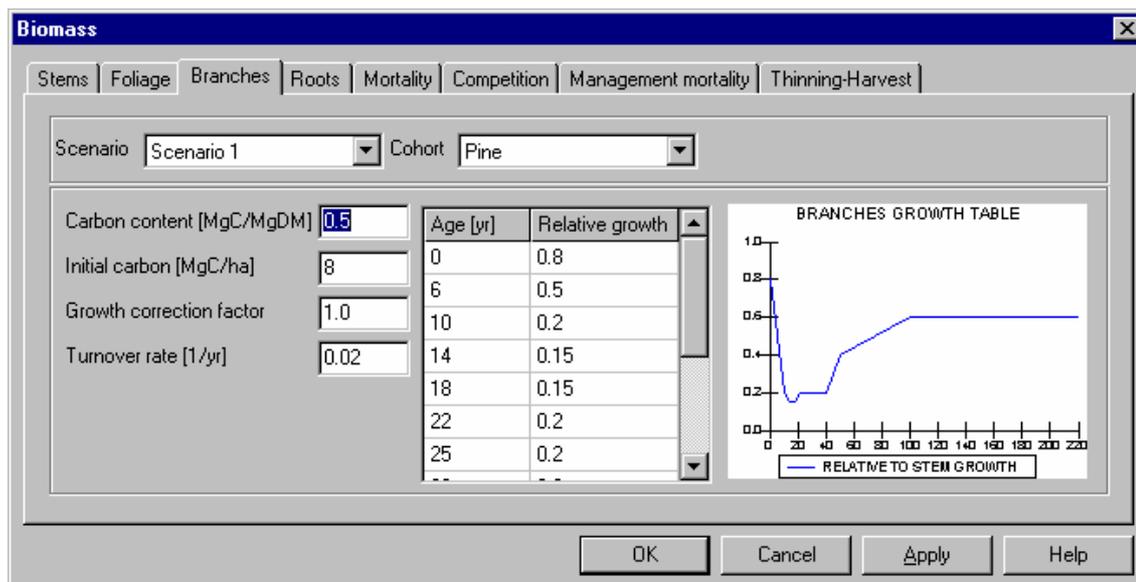
Figure 3.9. Branches parameterisation screen in main menu 'biomass'

Note also that there is no separate compartment for coarse roots and fine roots. This has implications for the turnover rate of the root compartment. Generally the turnover of fine roots is much higher than coarse roots, but the biomass of coarse roots increases during a rotation, whereas the biomass in fine roots shows less variation. In case of short rotations, there will be relatively more fine roots than in case of long rotations. Since turnover of fine roots is higher, total root turnover should be higher under short rotations than under long rotations.

Some literature data on root allocation and turnover can be found in Cairns et al. (1997), Gill and Jackson (2000) and Rasse et al. (2001). The parameterisation of the foliage, branches and roots compartments can be evaluated by checking simulated stocks against e.g. measured biomass data at different ages.

3.4.4   Mortality

Tree mortality within each cohort is separated into two causes, natural mortality (mortality due to senescence and competition) and mortality due to management activities. This section deals with the natural mortality only, for management mortality see the next section.

In CO2FIX the natural mortality is incorporated as a fraction of the standing biomass. This fraction can vary with age or with the ratio between actual and maximum attainable biomass, depending on the growth method chosen (see Figure 3.6). If growth (and thus mortality) is dependent on age, mortality may be high at low ages, simulating severe competition during early and dense stages (e.g. cohort 3 in Figure 3.10). When the initial planting density is low, initial mortality may be low as well (e.g. like cohort 2 and 3 in Figure 3.10). At middle ages mortality may be low, especially in the case of managed stands. When the trees approach their maximum

attainable age, mortality will increase again (cohort 1 and 2 in Figure 3.10). If growth is dependent on the ratio of actual biomass over maximum biomass, natural mortality should be parameterised according to this ratio as well.
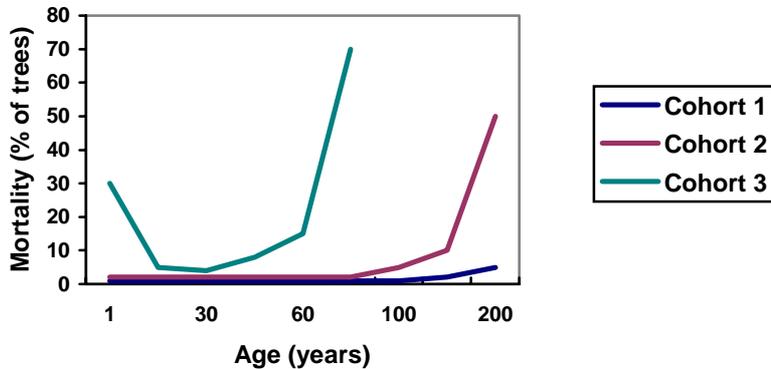
Figure 3.10. Mortality due to senescence of three cohorts parameterised as a function of stand age. Note that these are hypothetical curves displaying very high mortality rates, up to 70%.

The parameterisation of natural mortality (as a fraction of the standing biomass) is done in the **Biomass** main menu, tab **Mortality**. Figure 3.11 shows an example of the parameterisation of age-dependent natural mortality. For several ages, the fraction of the standing biomass that dies every year is defined. Data on natural mortality can generally be found from measurements of permanent forest inventory plots, specialised studies and sometimes it is included in growth and yield tables. Generally, natural mortality is strongly dependent on management intensity.
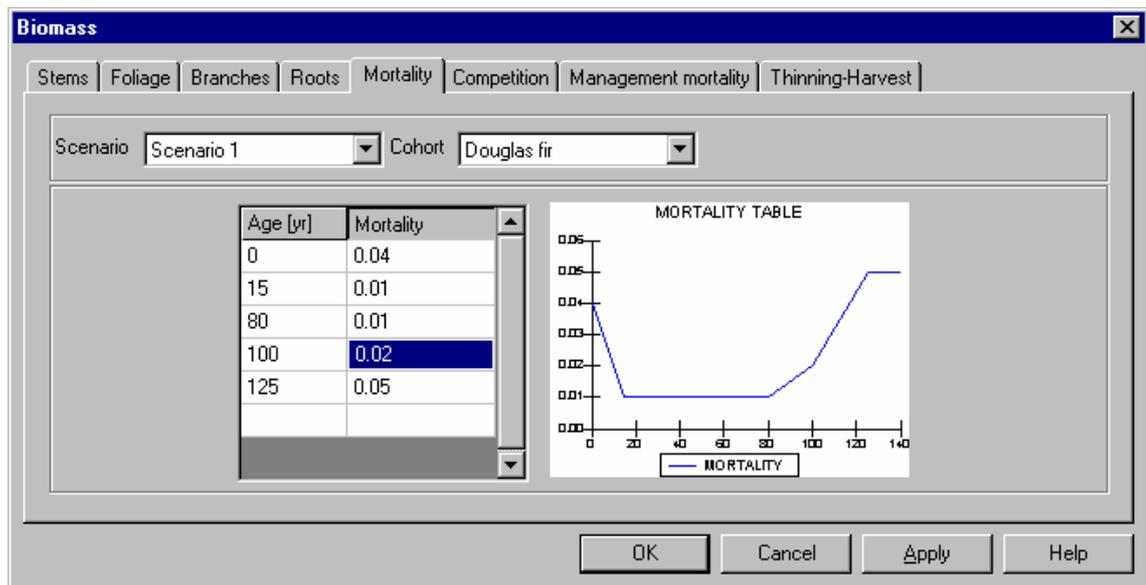
Figure 3.11. **Mortality** *parameterisation screen in main menu* **Biomass***.*

3.4.5 Management related mortality

Forest logging operations can damage the remaining trees in the stand, causing mortality even several years after the operation (Pinard and Putz, 1996). Traditional logging methods in tropical primary forests can cause mortality of the remaining trees up to 40% of the remaining stand (as measured in basal area) (Alder and Silva 2000). In many cases, mortality is high during the first years after the logging and decreases gradually over a period of 10-20 years, depending on the forest type, the technology used and the intensity of the logging operation (Pinard and Putz, 1996).

In CO2FIX, the mortality after logging depends on the intensity of the logging operation, expressed as the volume harvested per hectare. The user can define the initial mortality as a fraction of standing biomass and the impact time at various logging intensities. Mortality decreases linearly over time, reaching zero at the end of the impact time. In Figure 3.12, cases one and two, the mortality due to logging damage affects the remaining stand in a similar way through time, but depending on logging intensity (case one: 50 m^3; case two: 20 m^3). In case three low-intensity logging causes low initial mortality but the damage lasts long. In case four the initial mortality is low and the impact of damage is of short duration. For all cases: the cumulative percentage of mortality gives an idea of the total damage to the stand. In case two this amounts to about 55%.
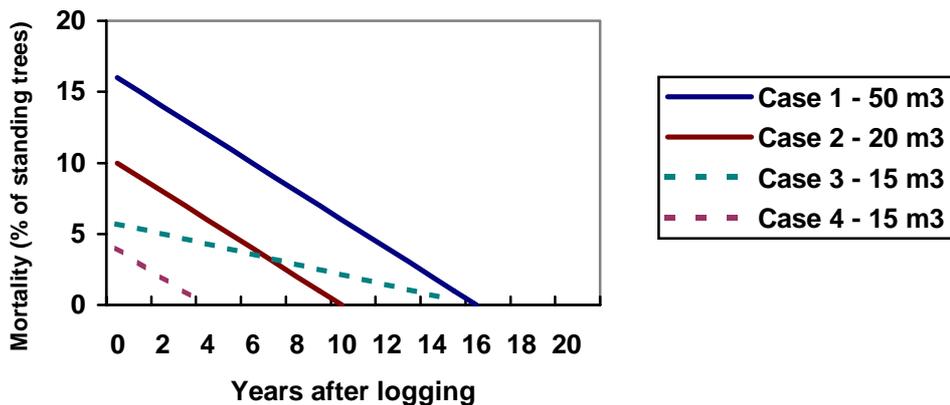
Figure 3.12. Mortality caused by damage from logging in four hypothetical cases, depending on the intensity of logging.

The management mortality in the model is linearly interpolated between the given mortality functions, depending on the intensity of logging. In case the logging intensity is higher than the highest parameterised intensity, the function for the highest logging intensity is used.

The user has two options for modelling the mortality due to logging damage:
a) Mortality as a function of total biomass removed, i.e. the mortality of the remaining trees in all cohorts is uniform and proportional to the remaining biomass of each cohort (default).

b) Mortality as a function of biomass removed from each cohort, i.e. the mortality of all the remaining trees in all the remaining cohorts depends on the degree of logging of the cohort logged.

The choice between these methods has to be made in the **General Parameters** main menu, tab *General parameters* (Figure 3.13). The other parameters can be found in the **Biomass** main menu, tab *Management mortality* (Figure 3.14).
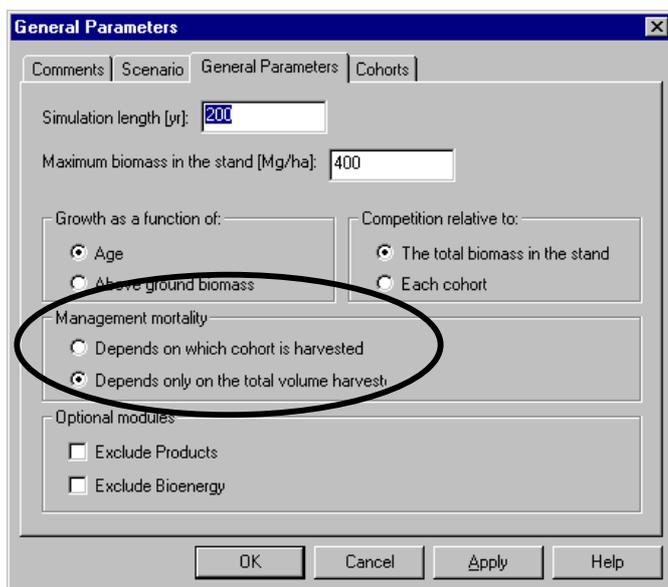
Figure 3.13. **General Parameters** *screen, in main menu* **General Parameters**, *with in this case management mortality as a function of the total volume harvested.*

If management related mortality is depending on the volume harvested per cohort, the annual mortality in the whole stand (all cohorts equally) that is caused by logging in the cohort chosen in the top of the window should be quantified. The mortality is parameterised as an annual fraction of the standing biomass, and for a certain impact time. If management mortality is dependent on the total volume harvested, the cohort box is not visible and mortality will be applied irrespective of the cohort harvested.
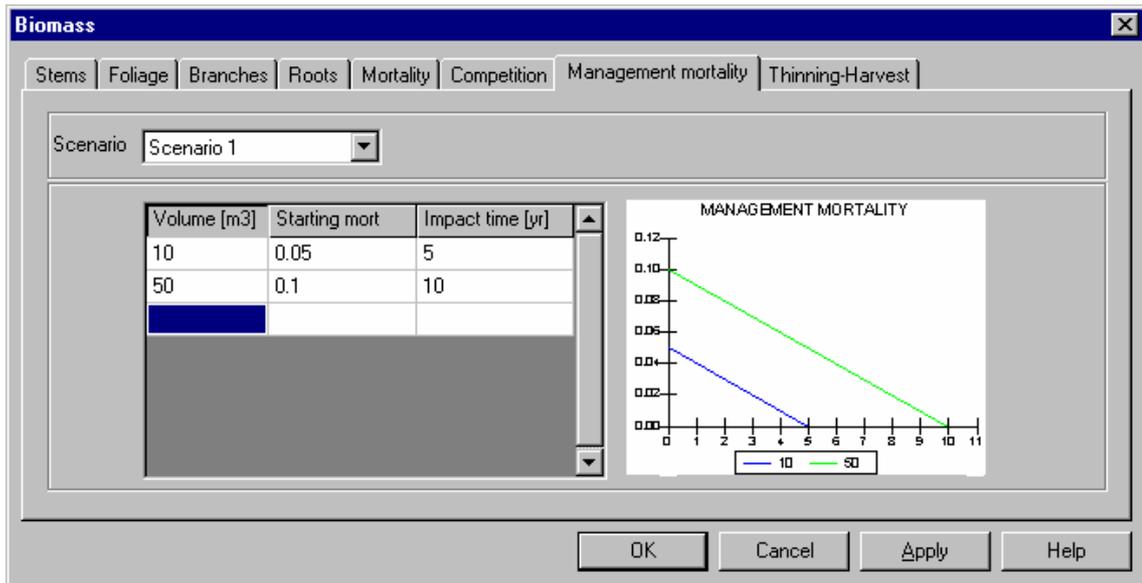
Figure 3.14. Parameterisation of management mortality, where management mortality is only dependent on the total volume harvested.

3.4.6 Interaction between cohorts (competition)

Tree growth is affected by interactions with neighbouring trees. Interaction effects can range from decreased growth (competition) via no effect to increased growth (synergic effects). The most important type of interaction is competition. For a cohort, the interaction can be caused by other individuals in the same cohort, or by individuals of other cohorts.

In CO2FIX, interaction is expressed as a parameter that modifies the current annual increment as it is given in the stem compartment. This growth modifier describes the influence of other individuals in the same cohort or the influence of other cohorts on the growth of the cohort in question. In Figure 3.15 we have three cases of interaction. Case 1 shows no competition, i.e. no growth reduction occurs at any stand density. This is the model default. In that case, any kind of competition is assumed to be included already in the yield table data. Case 2 shows no competition as long as the actual biomass is less than 50% of the maximum attainable biomass. At higher densities competition increases and the growth modifier decreases from 1 to 0.4. This is a typical situation for many forest stands. Case 3 shows an increase of the growth modifier up to 1.2 at low densities, but decreases at higher densities. Here we have synergy – there is a certain range of stand density, e.g. a mixture of two cohorts, where the growth is higher in the mixture than in the case of each cohort separately. This may be relevant in multi-species and multi-strata situations (e.g. Beer et al., 1990).
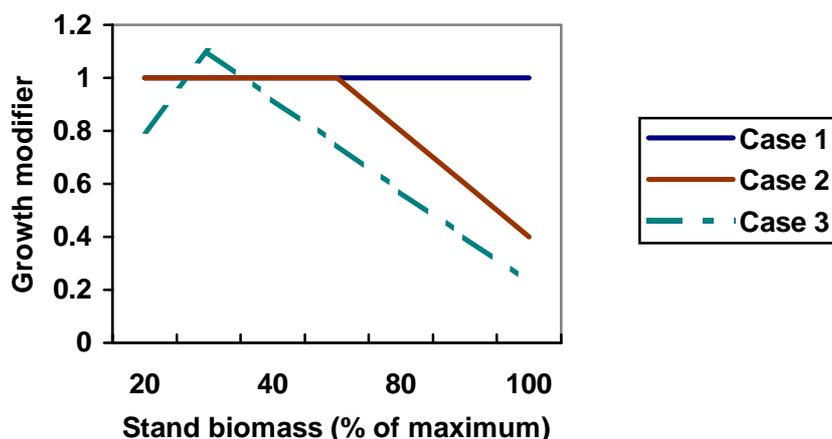
Figure 3.15. Growth modifier as a function of total stand biomass (Mg ha⁻¹) in three cases.

Within CO2FIX there are two options to define the growth modifier:

a) Interactions (competition) of a cohort as a function of total stand biomass (total biomass of all cohorts in a stand), i.e. the interactions of this cohort are with all the cohorts combined, including the cohort in question (default)

b) Interactions (competition) of a cohort as a function of biomass of each other cohort, i.e. the interactions of this cohort are defined with each other cohort separately

The choice between these methods has to be made in the **General Parameters** main menu, tab *General parameters* (Figure 3.16). The other parameters can be found in the **Biomass** main menu, tab *Competition* (Figure 3.17 and 3.18).
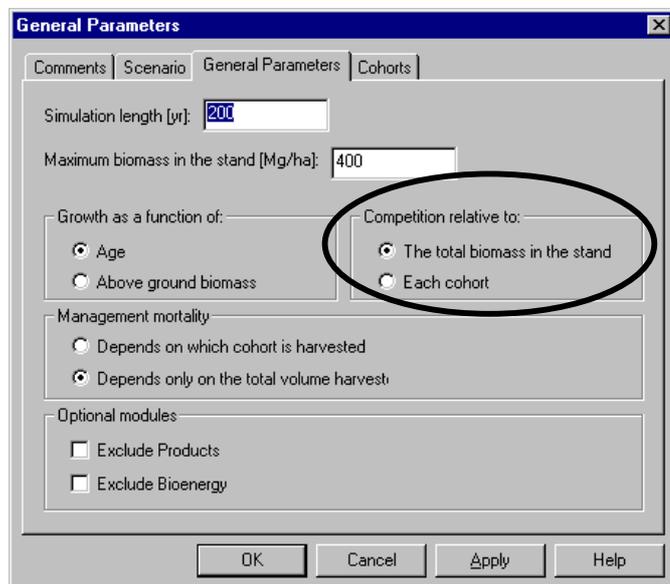
Figure 3.16. **General Parameters** *screen, in main menu* **General Parameters***, with in this case competition as a function of the total biomass in the stand.*

In case of option a), for each cohort (to be chosen in the top of the window) the user should insert how the density of the whole stand (actual biomass over maximum biomass) influences the growth of that cohort. An example of option a) is given in Figure 3.17.

In case of option b), the user can define for the cohort in the top of the window how all cohorts separately influence its growth. This is also done as a function of actual biomass over maximum biomass but then for each cohort separately. An example of option b) is given in Figure 3.18. In the example file CR_coffee_agroforestry.co2, an example of competition between cohorts for light can be found. Some more explanation about this case is given in Box 3.1.

In practice, there is very little information and data on interactions, especially in case of natural forests. In practical forestry situations these effects are already embedded in other variables, such as the growth and mortality. Therefore, the default is no competition.
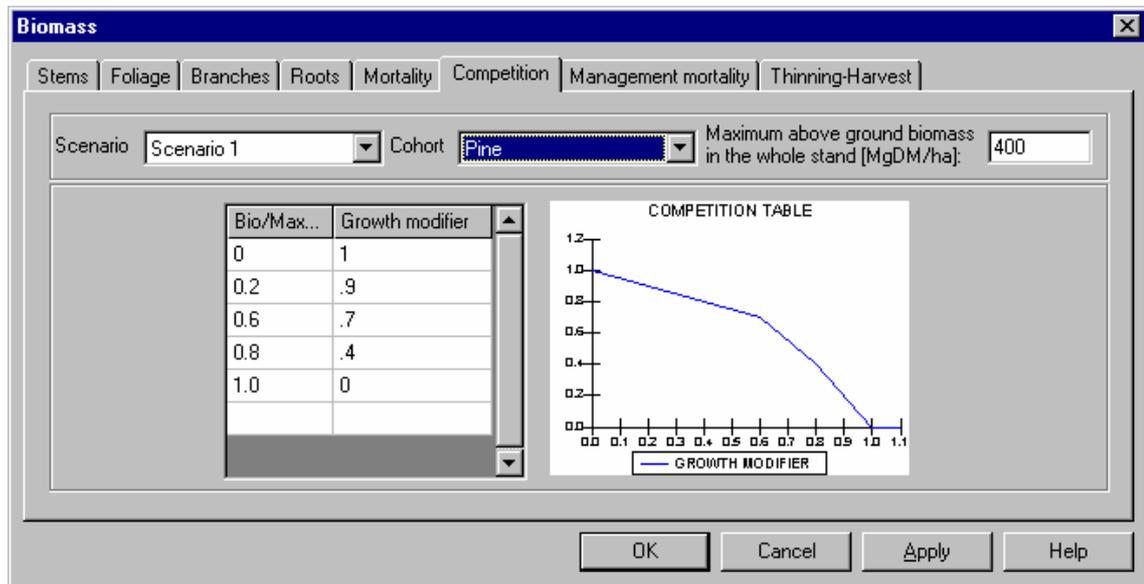
Figure 3.17. **Competition** *relative to total biomass in the stand*
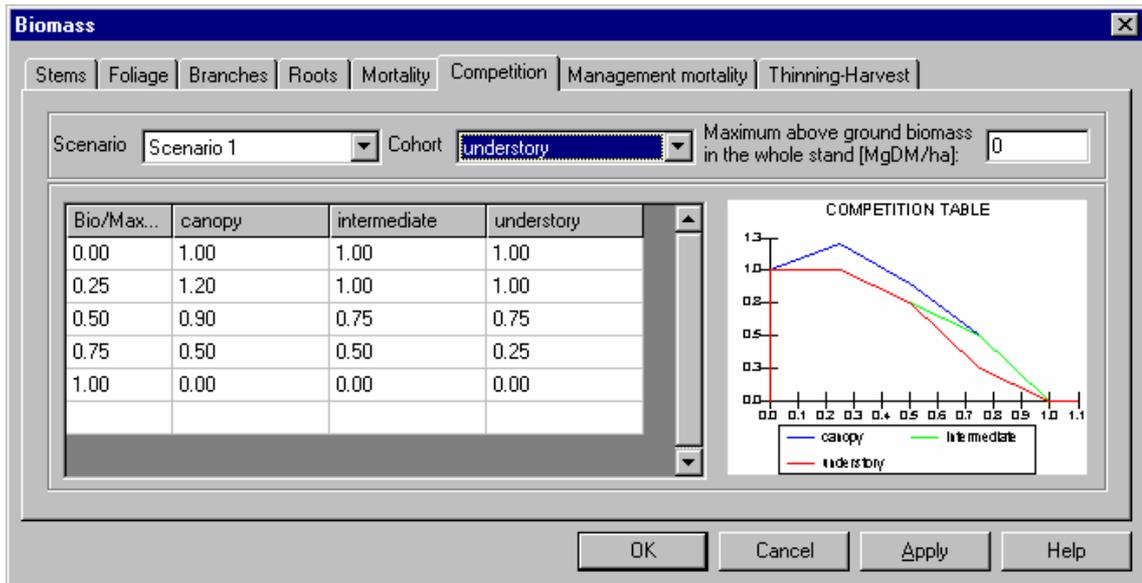
Figure 3.18. **Competition** *relative to each cohort. In this case is displayed how the understorey cohort is affected by all three cohorts.*

Box 3.1. Competition for light
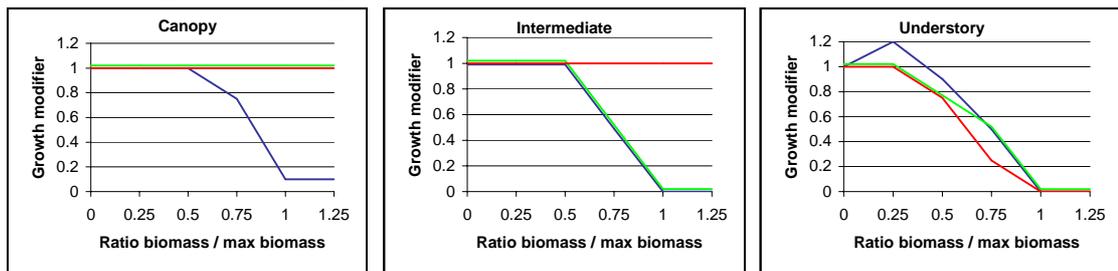
Competition for light, demonstrated for the case CR_coffee_agroforestry. Three cohorts are present, a canopy (blue), an intermediate layer (green) and an understory (red). The figures illustrate how each cohort is influenced by the presence of other cohorts. The growth of the canopy (left figure) is only influenced by itself. The presence of other layers does not affect the growth of the canopy layer. The growth of the intermediate layer (middle figure) is influenced by itself and by the presence of a canopy layer. The presence of an understory has no influence. The growth of the understory is affected by all three layers. The presence of a light canopy even enhances the growth of the understory.

3.4.7 Management interventions (harvesting)

Within CO2FIX, two types of management interventions are possible: thinning and final felling. Other management activities like drainage and fertilization cannot be parameterised, but their effects can be inserted by changing the current annual increment data (see also 'special parameterisations'). Thinning and final felling can be defined for each cohort separately. A thinning is described by the following parameters:

a) Age at which the intervention takes place;
b) Intensity of the intervention (fraction of cohort biomass removed);
c) Allocation of the biomass removed to different 'raw material' classes as slash, logwood and pulpwood.

A final felling can be simulated in the model by a thinning where 100% of the biomass is removed. In case of a management intervention, all biomass compartments are reduced according to the specified intensity. Stemwood and branches can be allocated to logwood, pulpwood or slash. Foliage is always regarded as slash and roots are always regarded as litter. It is possible to re-allocate the slash partly or totally to the firewood raw material class, to simulate fuelwood collection. See also the products module description for more information.

Parameters concerning the management can be found in the **Biomass** main menu, tab ***Thinning-Harvest*** (Figure 3.19). For each thinning to be carried out (in the cohort chosen in the top of the window), a row should be inserted in the table. At each row, the age should be inserted (first column) and the *fraction* of trees/biomass to be removed. Furthermore, the initial allocation of harvested stems and branches over logwood, pulpwood and slash should be defined. The column *Slash* is always updated automatically (grey fields), where Slash = 1- (logwood + pulpwood). Foliage is automatically added to slash. The last two columns define the allocation of slash between *firewood* and input to the *soil* (litter). The last row entered in the table is regarded as the end of the rotation. If this is a final harvest, a '1' under '*fraction removed*' should be entered to remove all stems and biomass. However, this fraction can be lower than 1 to simulate some living trees left at the site. In this way it is also possible to simulate regular interventions in unevenaged forests, where for example every 25 years 10% of the commercial trees is harvested. If growth is driven by age, the cohort will start growing according to age zero after the end of the rotation, even if not all trees were harvested. The rotation length that will be applied is shown in the upper right box.

Biomass

| | Stems | Foliage | Branches | Roots | Mortality | Competition | Management mortality | Thinning-Harvest |

Scenario [Scenario 1 ▼] Cohort [Pine ▼] Rotation length [yr] [50]

Age [yr]	Fraction Removed	Stems LogWo...	Stems PulpPap	Stems Slash	Branches LogWo...	Branches PulpPap	Branches Slash	Foliage Slash	Slash FireWood	Slash Soil
10	0.200	0	0	1.00	0	0.00	1.00	1.00	.9	0.10
20	0.350	0	0	1.00	0	0	1.00	1.00	.9	0.10
30	0.350	0	0	1.00	0	0	1.00	1.00	.9	0.10
40	0.350	0	0	1.00	0	0	1.00	1.00	.95	0.05
50	1	0	0	1.00	0	0	1.00	1.00	.95	0.05

[OK] [Cancel] [Apply] [Help]

Figure 3.19. Thinning and final harvesting table

3.5 Soil module

3.5.1 Applicability

In CO2Fix, the dynamic soil carbon model Yasso (Liski et al., in prep., http://www.efi.fi/projects/yasso/) is used. The model describes decomposition and dynamics of soil carbon in well-drained soils (soils in which poor drainage does not slow down decomposition).The current version is calibrated to describe the total stock of soil carbon without distinction between soil layers. The model can be applied for both coniferous and deciduous forests. It has been tested to describe appropriately the effects of climate on decomposition rates of several litter types in a wide range of ecosystems from arctic tundra to tropical rainforest (Liski et al., 2003a, Palosuo et al. In prep.).

3.5.2 Structure

The soil module consists of three litter compartments and five decomposition compartments (Figure 2.2). Litter is produced in the biomass module through biomass turnover, natural mortality, management mortality, and logging slash (see biomass module for a description of these processes). For the soil carbon module, the litter is grouped as non-woody litter (foliage and fine roots), fine woody litter (branches and coarse roots) and coarse woody litter (stems and stumps). Since the biomass module makes no distinction between fine and coarse roots, root litter is separated into fine and coarse roots according to the proportion between branch litter and foliage litter. Each of these litter compartments has a fractionation rate determining the proportion of its contents released to the decomposition compartments in a time step. For the compartment of non-woody litter, this rate is equal to 1 which means that all of its contents are released in one time step, whereas for the woody litter compartments this rate is smaller than 1. Litter is distributed over the decomposition compartments of extractives, celluloses and lignin-like compounds according to its chemical composition. Each decomposition compartment has a specific decomposition rate, determining the proportional loss of its contents in a time step. Fractions of the losses from the decomposition compartments are transferred into the subsequent decomposition compartments having slower decomposition rates while the rest is removed from the system. The fractionation rates of woody litter and the decomposition rates are controlled by temperature and water availability.

The parameters for the soil module can be found under the **Soil** main menu. The soil module consists of two tabs, ***General Parameters*** and ***Cohort Parameters***. In the ***General Parameters*** tab the user needs to provide climate parameters for the site (Figure 3.20). These are effective temperature sum (*degree days* above zero) over the year (°C d), *precipitation in growing season* (mm), and *Potential evapotranspiration in growing season* (PET, mm). Temperature and precipitation data may be found at for example http://www.worldclimate.com. CO2FIX can calculate degree days above zero and potential evapotranspiration from mean monthly temperatures. This can be done by

activating the *Calculate button*. In the Calculate climate window (Figure 3.21), monthly temperatures can be specified, as well as which months are considered as growing season. It is important to note that CO2FIX V 3.1 uses effective temperature sum as the temperature variable, not annual mean temperature like V 2.0 did.

Figure 3.20. Main window for the **Soil** *module.*

Figure 3.21. Calculate climate window, with in this case a growing season from May till September.

For each *cohort* in each scenario, the carbon stocks in each soil compartment (i.e. the boxes in Figure 2.2) must be initialised. This can be done through manually inserting available data in the **Cohort** parameters tab (Figure 3.22), or initial stocks can be calculated by providing litterfall rates of the vegetation on the site before the current case study. This latter option can be activated by the *Calculate initial carbon* button. In

the *Equilibrium* window (Figure 3.23) the litterfall rates can be specified. Those litterfall rates can among others be derived by parameterising and running the previous vegetation/land-use in CO2FIX.

Figure 3.22. Soil initial stocks per compartment in the soil module.

Figure 3.23. Window to initialise soil carbon stocks through litterfall rates of the previous land use.

On the **Cohort** parameters tab is a button '*Yasso model parameters*'. Under this button, the user can give specific parameter values of *chemical litter quality*, the *temperature sensitivity* parameter and the *initial decomposition* parameter (Figure 3.24). Two default sets of parameters are available, one for conifers and one for broadleaves. Usually these defaults are used, unless site-specific data are available.

Figure 3.24. Soil module internal parameters.

3.6 Products module

3.6.1 General

The products module tracks the carbon after harvesting. In the same year as the harvest takes place, several intermediate processing and allocation steps are done, until the carbon resides in the end products, the millsite dump, or is transferred to the bioenergy module (Figure 2.3). When end products are discarded at the end of their lifespan, they can be recycled, deposited in a landfill, or they can be used for bioenergy, which is taken care of in the bioenergy module. Carbon is released to the atmosphere through decomposition at the millsite dump, at the landfill, or via the bioenergy module. This module is based on a model developed and used before by Karjalainen et al. (1994) for modelling the carbon budget for the Finnish forest sector. A more detailed version has been applied for the European forest sector (Karjalainen et al., 2002, Eggers, 2002). Two default parameters sets are delivered with the model, a set with high processing and recycling efficiency and a set with low processing and recycling efficiency.

All parameters concerning the products module can be found under the **Products** main menu. New is the option Exclude products (in **General Parameters**, see Figure 3.25). This option should be used when simulating 'real world' carbon crediting projects, since products are to be excluded according to the Marrakech accords.
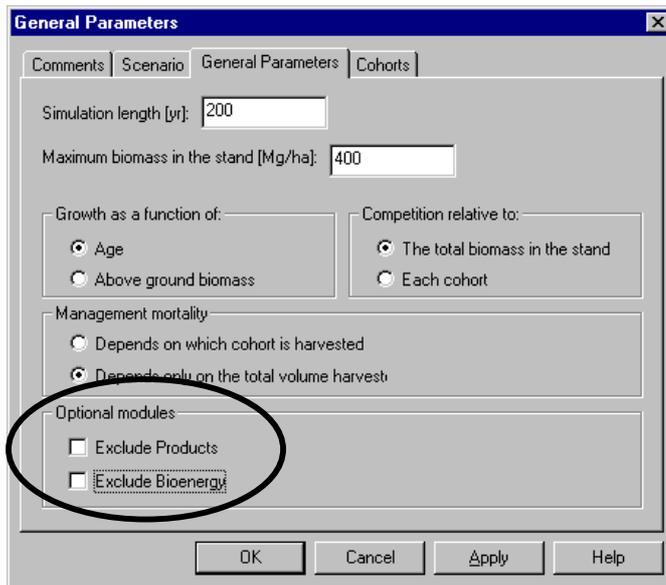
Figure 3.25. **General Parameters** *screen, in main menu* **General Parameters***, with the options to exclude the products module and/or the bioenergy module.*

3.6.2 Production line

The first tab, **Production line**, contains the parameters for the processes of raw material allocation and process losses (Figure 3.26). The top part of the window

concerns the raw material allocation. Pulpwood and logwood are distributed to the commodities sawnwood, boards & panels, pulp & paper and bioenergy. The firewood/bioenergy value is automatically updated, in such a way that the sum of the fractions is 1. In the bottom part of the window, the user can specify what happens with the process losses within the production line of each commodity. Process losses can be re-used in 'lower grade' production lines, can be used as firewood/bioenergy, or can be dumped at the mill site. The total of the fractions in each line is the total process loss, so 1 minus this total is the processing efficiency.

Figure 3.26. Parameterising the products module: raw material allocation and processing losses

3.6.3   End products

The second tab, **End products**, contains parameters for the end products allocation process and the end of life process (Figure 3.27). The top part of the window allows the user to define for each commodity (sawnwood, board, paper) which fraction is used for long, medium and short term products. These allocations will sum to 1 because
short term = 1-(long term + medium term)

The bottom part of the window in Figure 3.27 describes the fate of the products at the end of its life. The user should define which fraction of the discarded products is recycled and which fraction is burned (used for bioenergy). The rest of the products are assumed to be dumped in a landfill.

Figure 3.27. Parameterising the products module: life span allocation and end-of-life disposal

3.6.4 Life span for products in use and recycling

The third tab, **Recycling_life span**, contains the life spans of the three product groups, the landfill and millsite dump, and it contains the parameters for the recycling process (Figure 3.28). The top part of the window allows parameterisation of the recycling between groups of life spans. A product can only be recycled to the same life-span category or lower. The rows should sum to one, since the fraction that is recycled, is defined earlier, these parameters concern only the allocation over the different life spans.

The bottom part of the window provides the parameterisation of life spans of the three product groups the landfill and millsite dump. An exponential discard/decay over time is used in CO2FIX V 3.1 (Figure 2.4). The life span parameter defines the half life, so a life span of 15 years means that after 15 years, 50% of the original amount of carbon is left. On average, the life span will then also be 15 years. For the product groups, the end of life can result in recycling, using the wood as fire wood (bioenergy), or dumping the wood in a landfill. For the millsite dump and for the landfill, end of life will result in the actual release of carbon.
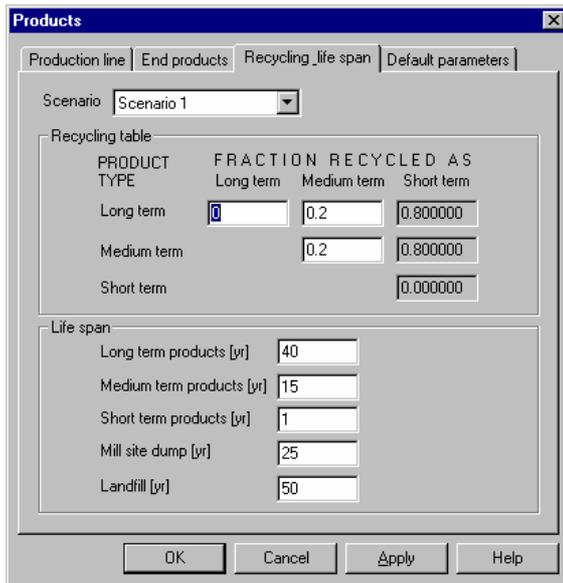
Figure 3.28. Parameterising the products module: way of recycling and life spans

3.6.5 Default parameters

Under the **Default parameters** tab, two sets of default parameters can be loaded (Figure 3.29). These are a high and a low processing efficiency parameter set. Further, own parameter sets can be saved here for use in other scenarios and case studies. With the *Load* button, the specified parameter set can be loaded. The *Save* button provides the possibility to save the current set of parameters under a new name. The *Update* button will update the specified default set with the current parameters. The *Delete* button will delete the selected default set.
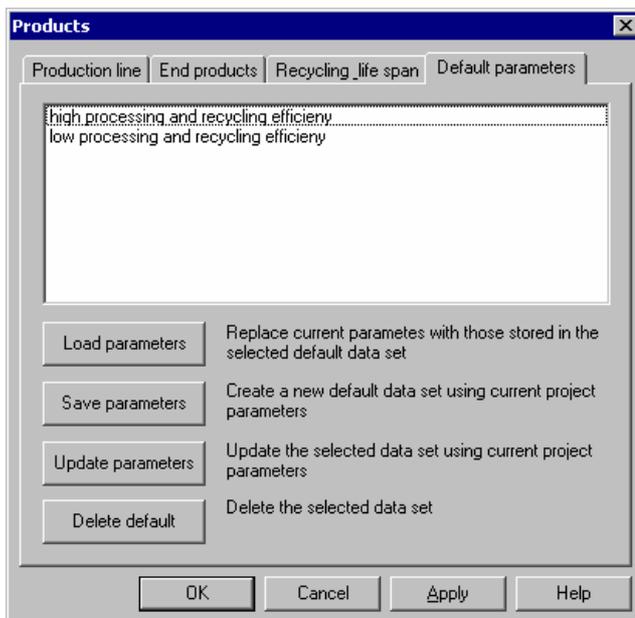
Figure 3.29. Parameterising the products module: choosing sets of parameters.

3.7 Bioenergy module

3.7.1 General

The bioenergy module calculates the carbon mitigation due to substituting biomass for fossil fuels and improving the efficiency of biomass combustion. The bioenergy carbon mitigation depends on the following general parameters: i) Amount of biomass fuel (fuelwood) produced annually (i.e., the input source); ii) Energy content of fossil and bioenergy fuel (slash and industrial fuel wood); iii) Efficiencies and Emission factors of the current and alternative technologies.

3.7.2 Input sources:

The annual input fuelwood for the mitigation calculation is taken from the biomass module and from the products module. It is categorized as follows:
- Slash fuelwood; the 'slash firewood' coming from the Thinning-Harvest tab from the Biomass module
- Industrial residues fuelwood; the raw material and process losses disposed to bioenergy at the product's Production line tab, and products at their end of life disposed to Energy.

The two input sources may be associated to different bioenergy technologies. For example, all the biomass produced in the forest may be directed to slash firewood in a bioenergy plantation directed to electricity generation. On the other hand, the residues produced at a sawmill by a forest managed for timber production, may end-up as input of a residential heating facility. For these reasons, the carbon mitigation is executed separately for each of the two main input sources.

3.7.3 Parameters dialog:

The bioenergy parameters can be found under the **Bioenergy** main menu. Within this menu, three tabs are available:
- **General parameters** tab to set-up the parameters involved in both slash fuelwood and industrial residues fuelwood calculations and in all scenarios (Figure 3.30)
- **Technology for slash firewood** tab to enter parameters for each scenario's carbon mitigation calculations for slash firewood based alternative technologies and
- **Technology for industrial residues firewood** tab to enter parameters for each scenario's carbon mitigation calculations for industrial firewood based alternative technologies.

The **General Parameters** tab has default values for the *global warming potential* (GWP) associated to the different GHG under consideration, and default values for the *heating value* associated to slash firewood and industrial firewood (Figure 3.30). If needed, these default values can be replaced by other values by the user.

Figure 3.30: **General Parameters**

In the **Technology for Slash Firewood** and **Technology for Industrial Firewood** tabs the users needs to set up the efficiency, heating value, and GHG *emission factors* of the *fuel & technology to be substituted* (in general, a fossil fuel based technology, but could also be an old biomass system to be replaced for the purposes of carbon mitigation) and for the alternative *fuel & technology* (Figure 3.31).

In this case, the user can either enter the values one by one using their own data sources, or rather choose a default fuel/technology from a built-in database (Figures 3.32 and 3.33) by using the Select button in each fuel/technology section. These values are loaded from a text file called bioenergy_data.txt, which can be edited using a text editor.

Figure 3.31: **Technology for Slash Firewood**

Figure 3.32: Selecting current fuel & technology

Figure 3.33: Selecting alternative fuel & technology

All the parameters associated to the **Technology for Slash Firewood** and **Technology for Industrial Firewood** can be set up on a scenario basis just like other modules.

3.7.4 Parameters validation:

When the total emissions from the chosen alternative technology are higher than those from the substituted technology, the result will be negative carbon mitigation. In such cases a warning will appear, indicating for which situation (scenario number and slash fuelwood or industrial residues firewood) the carbon mitigation shows a negative result.

3.7.5 Enabling / disabling the Bioenergy Module:

The Bioenergy Module can be enabled/disabled at the general parameters dialog. The basic input to the model (fuelwood coming from both slash and industrial sources) is taken from the products module, so the Bioenergy Module depends on

the Products Module to be enabled. Disabling the Bioenergy Module prevents all mitigation calculation and carbon mitigation increment to the scenario total carbon stock in the scenario. The bioenergy output columns can be hidden from the carbon stocks table by using the carbon stocks table view options, but this does not prevent the bioenergy mitigation carbon from being added to the total scenario carbon stock.

3.8 Forest financial module

Costs and benefits are assessed in CO2Fix V 3.1 with a simple module. Different types of cost and benefit inputs have to be specified by the user. The model will calculate the costs and benefits, the discounted costs and benefits and the Net Present Value (NPV). Note that the financial module only takes into account the direct revenues from the forest and not any added value from end products farther away in the wood products chain.

Parameters for the financial module can be found under the **Finance** main menu. This menu contains three tabs: ***Management Costs, Management Returns*** and ***Other Returns and Costs*** (Figure 3.34). In the ***Management Costs*** tab you can specify per *scenario* and *cohort* the costs directly related to the management. In the left side of the window *costs related to thinnings and final harvest* can be specified. The age at which a thinning will take place is specified already in the **Biomass** module. Note: these ages cannot be changed here, nor can these rows be deleted here. That should be done in the biomass module. At the right side of the window other age *related costs* can be specified. These are separated in fixed costs, such as costs of (re)planting, and recurring costs. Note that these costs are related to the age of the cohort.

In the ***Management Returns*** tab, you can specify the revenues of the management. For revenues of timber harvest, the *stumpage price* of pulp logs, saw logs and firewood must be specified. This is in the model combined with the amount of wood that will be harvested to calculate the total revenue. In the right side of the window *fixed and recurring revenues* that are related to the age of the cohort can be specified.

In the ***Other Returns and Costs*** tab costs and revenues related to the simulation year can be specified per scenario, both divided in *fixed* and *recurring* issues. Recurring costs can be for instance property taxes on the forest. These are not related to the actual age of the cohort(s) standing on it. Furthermore, the discount rate can be inserted in this tab.
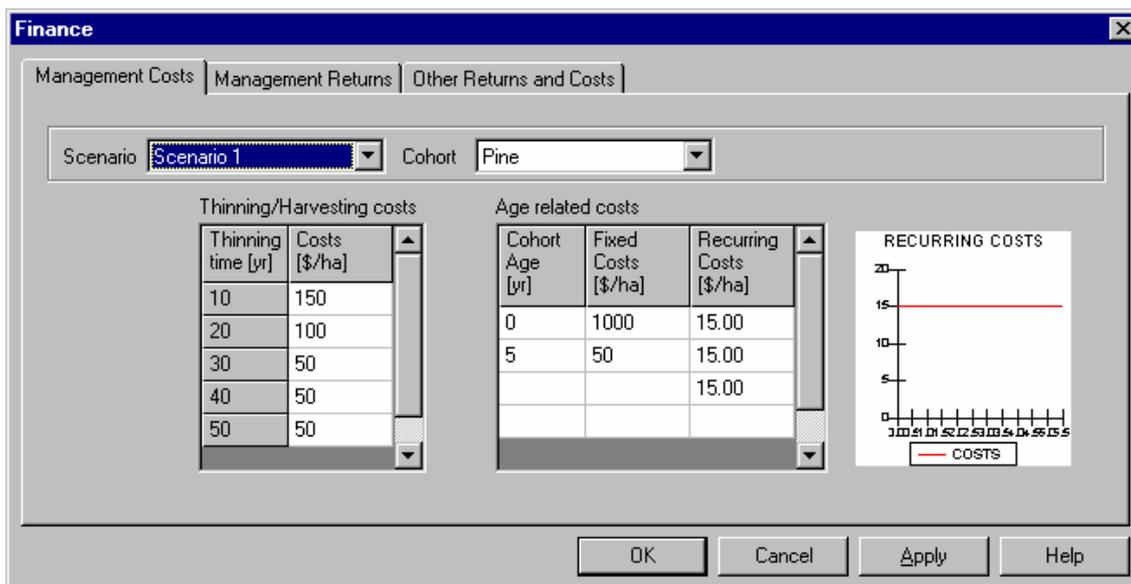
Figure 3.34. The parameterisation of the **Financial** *module.*

3.9 Carbon accounting module

In the past, many methods have been developed and proposed to calculate carbon credits. At the CoP9 meeting in December 2003, the exact carbon crediting methods were settled, as well as the eligible carbon pools (Decision 19/CP.9, see for the exact text http://unfccc.int/resource/docs/cop9/06a02.pdf).

Carbon pools eligible for carbon credit issuance for afforestation or reforestation project activities under the CDM are above-ground biomass, below-ground biomass, litter, dead wood and soil organic matter.

Temporary CER or **tCER** is a certified emission reduction (CER = 1 Mg of CO_2e) issued for an afforestation or reforestation project activity under the CDM which expires at the end of the commitment period following the one during which it was issued. A tCER can be used only in the commitment period for which it was issued. When it expires, its buyer must replace it in full.

Long-term CER or **lCER** is a certified emission reduction (CER) issued for an afforestation or reforestation project activity under the CDM, which expires at the end of the crediting period (20 or 30 years) of the afforestation or reforestation project activity under the CDM for which it was issued. An lCER can be used in the commitment period for which it was issued. It cannot be carried over to subsequent commitment periods. When expired, it must be replaced in full. If an lCER is reversed then it must be replaced in the current commitment period.

The **crediting period** can be 20 or 30 years, and can be extended once in the case of a period of 30 years, and extended twice in case of a period of 20 years, leading to a maximum crediting period of 60 years.

The difference between tCERs and lCERs is that tCERs are valid only until the end of the next commitment period, whereas lCERs are valid until the end of the crediting period. If the net sequestration is monotonically increasing then there are always credits being generated (Figure 3.35). If there is a period of net loss of carbon during the crediting period (e.g. due to harvesting), then there is the potential for reversal of lCERs (Figure 3.36 and 3.37). The project proponent may decide to sell all lCERs issued, but may have to offer a discount for lCERs that will be reversed before the end of the crediting period (Figure 3.36). Alternatively, the project proponent may choose to retire (or not sell) the lCERs that would be reversed in the next period (Figure 3.37). This would mean that they would not need to be replaced. All tCERs can be sold regardless of the potential loss of carbon (ENCOFOR, 2004).

tCERs & lCERs
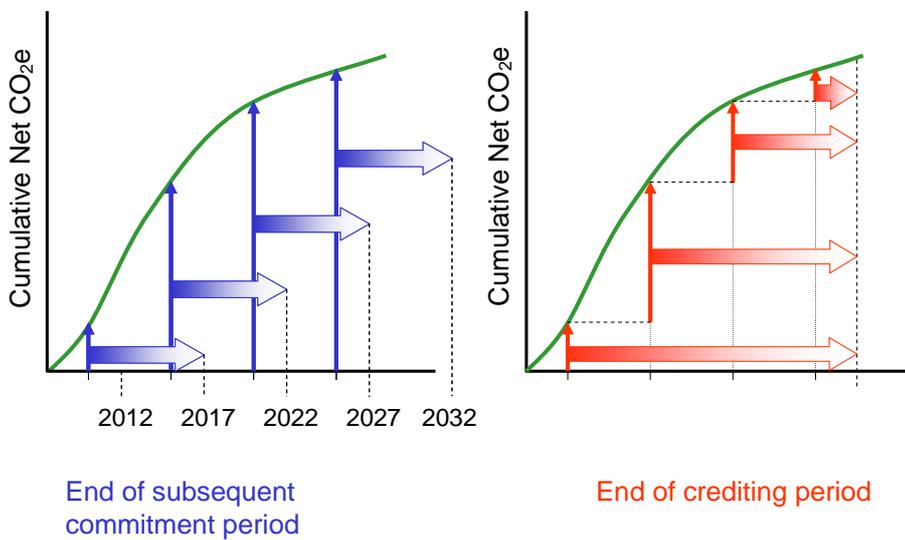
Figure 3.35. TCERs and lCERs in case of monotonically increasing carbon stocks (ENCOFOR, 2004).
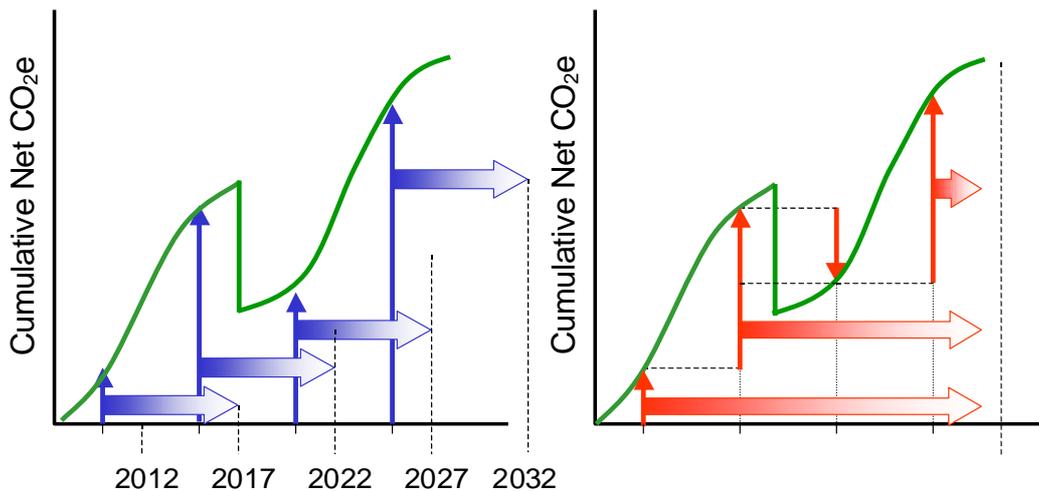
Figure 3.36. TCERs and lCERs in case of fluctuating carbon stocks, with reversal (ENCOFOR, 2004).
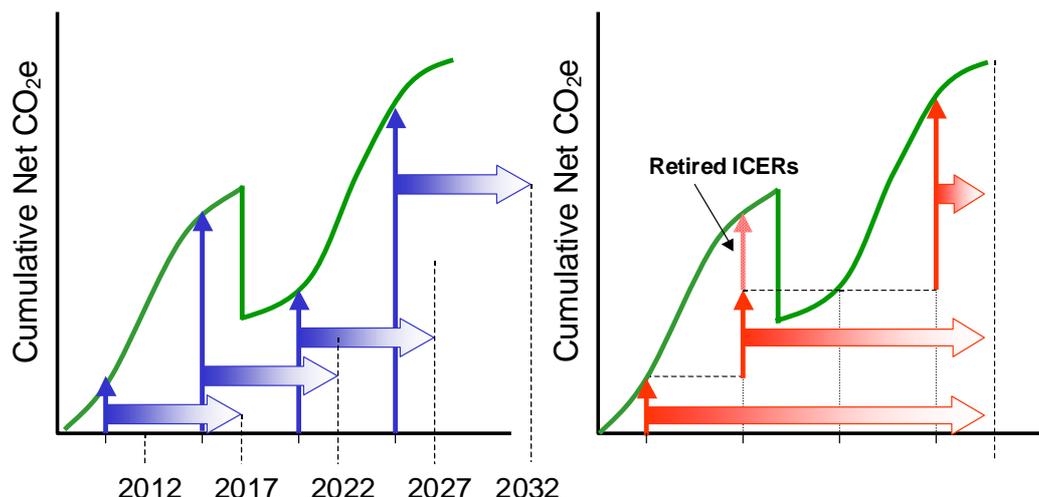
Figure 3.37. TCERs and lCERs in case of fluctuating carbon stocks, without reversal (ENCOFOR, 2004).

A requirement for certain types of projects under the Kyoto Protocol is a baseline scenario. This baseline scenario defines what would have happened if the project was not initiated. Therefore, in CO2FIX V 3.1, different scenarios can be specified, for example a baseline scenario and one or two mitigation scenarios. The definition of these scenarios is done in the main menu **General Parameters**, tab **Scenario** (Figure 3.38).
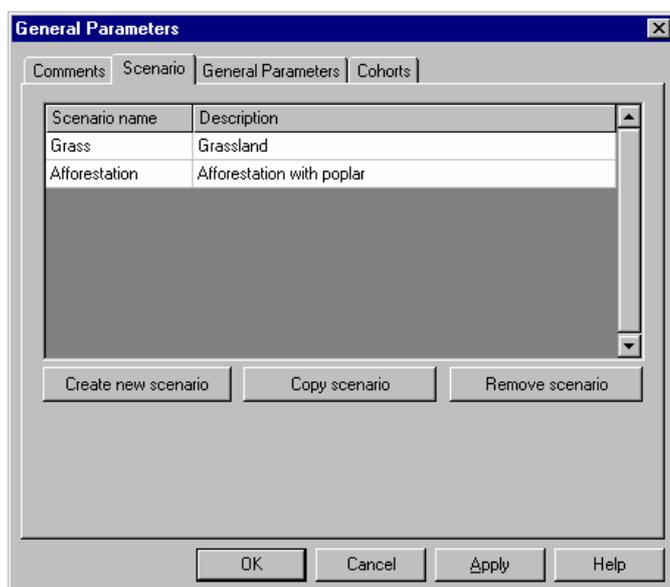
Figure 3.38. The definition of different scenarios.

The other parameters concerning the carbon accounting module can be found under the **Carbon Accounting** main menu. The **Carbon Accounting** module consists of two tabs, **Carbon Accounting** and **Kyoto Protocol**. The **Carbon Accounting** tab contains all parameters concerning the carbon accounting, the **Kyoto Protocol** tab provides the user with some help concerning the Kyoto Protocol and different types of projects.

Under the **Kyoto Protocol** tab, the *type of project* you are investigating must be selected (Figure 3.39). At the bottom of the window a short description of the type of project and some of its requirements will be visible. To determine the type of your project, you can click the *Assist* button. By answering the questions, you will be guided through a decision tree and so find out what type of project you have.
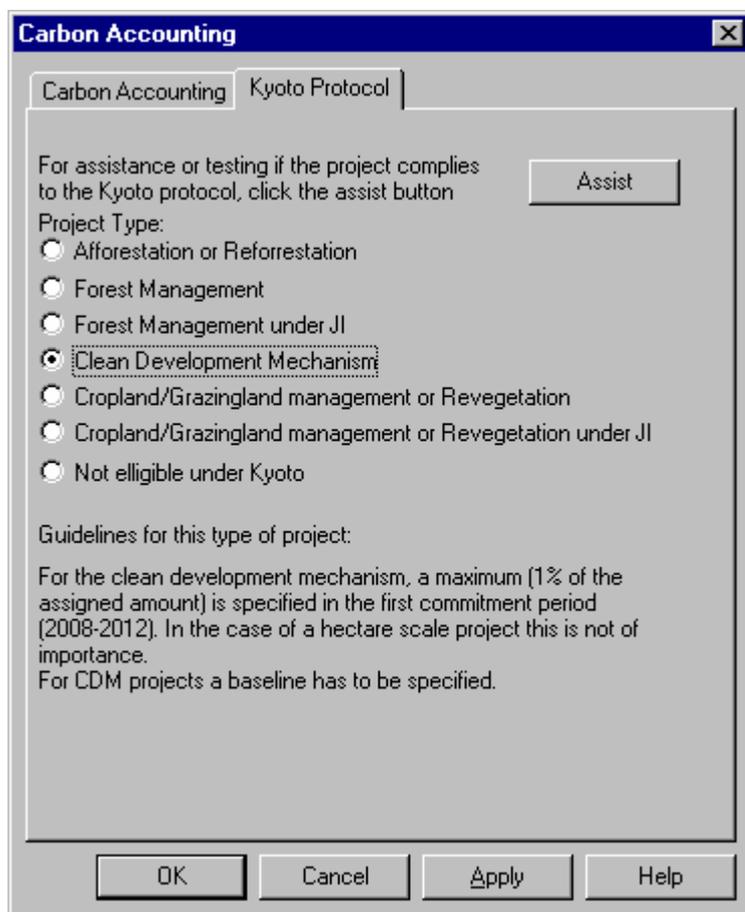
Figure 3.39. The **Kyoto Protocol** *tab, showing the choice between different kinds of projects.*

The first parameter in the **Carbon Accounting** tab is the *start year for crediting period* (Figure 3.40). This refers to the simulation year as displayed in the output. So if you start your simulation in 1985 and you want to start the crediting in 1990, year 5 should be entered here. The first verification has to be within 5 years of the start of the crediting period. Therefore, the *year of first verification* is limited to a few values, depending on your starting year. CO2FIX will give you a warning if this requirement is not fulfilled. The *duration of crediting period* is limited to 20, 30 40 or 60 years, as explained above.

In the next boxes, the user can define which scenario to take as *baseline* and which as *mitigation* scenario. A baseline scenario is not always required, but depends on the type of project. The user can check this under the **Kyoto Protocol** tab. In case a baseline is required, but no baseline is specified, a baseline of 0 is assumed, which is reported in a warning. In case a baseline is not required, but still selected, the baseline

is incorporated in the calculations, but a warning will appear. In case a certain scenario is selected as baseline or mitigation, but is deleted in the General Parameters window (Figure 3.38), the user will be forced to choose a new scenario instead. In the *Carbon stock* box the compartments that will be included in the carbon crediting scheme can be specified. If soil and biomass should be evaluated together, here *Total* should be used, and in the **General Parameters** screen the option *Exclude products* should be activated (Figure 3.25).

In the output of the carbon accounting module, the amount of sequestered carbon in the project is shown, for the selected carbon stocks only and taking into account the selected baseline and mitigation scenario. Since the credits are expressed in CO2 equivalents, also the CO2 equivalents are shown. The carbon accounting module does not take into account leakage outside the project, and does not consider other greenhouse gasses than CO_2. Results of the bioenergy module are not taken into account. Within the crediting period, tCERs and lCERs (with and without reversal) are shown, as well as their respective lifespans. If costs and revenues have been specified in the financial module, the net present value (NPV) per credit will be shown as well. However, tCERs and lCERs can be issued for CDM afforestation or reforestation projects only. For other project types, the stock change approach is shown. This is simply the difference between the carbon stock at a certain point in time and the start year of the crediting period.

Figure 3.40. The parameters for carbon accounting.

3.10   Output

The output of CO2FIX can be viewed as graphs or as tables. In the main menu, six buttons are available:
- 'View stocks table' icon to generate a table that shows all kinds of stocks;
- 'View flow table' icon to generate a table that shows all kinds of fluxes;
- 'View financial output' to generate a table that shows all (discounted) costs and revenues and NPVs;
- 'View carbon credits' to generate a table that shows carbon credits and costs per credit for the different methods
- 'View chart output' icon to view simple ready-made charts of the output,
- 'View options' icon to select alternatives for the ready-made charts and tables.

All tables can be exported to a flat text file that can be imported in e.g. Excel with the Excel button (the fourth button from the left). The ready made charts (Figure 3.41) can easily be altered through the 'view options' icon. A screen with the different options will appear (Figure 3.42). This allows viewing stocks of carbon, dry weight, volume or current annual increment for total biomass, by scenario and cohort, or for the soil or products compartment. Also a comparison between scenarios is possible, as well as a chart with the development of carbon credits under the different methods over time. With the introduction of scenarios and the bioenergy module, it is possible to produce negative values if the mitigation scenario or technology is less than the baseline. However, the interface of the model is not yet able to show these negative values, since the x-axis is fixed at the bottom of the graph.
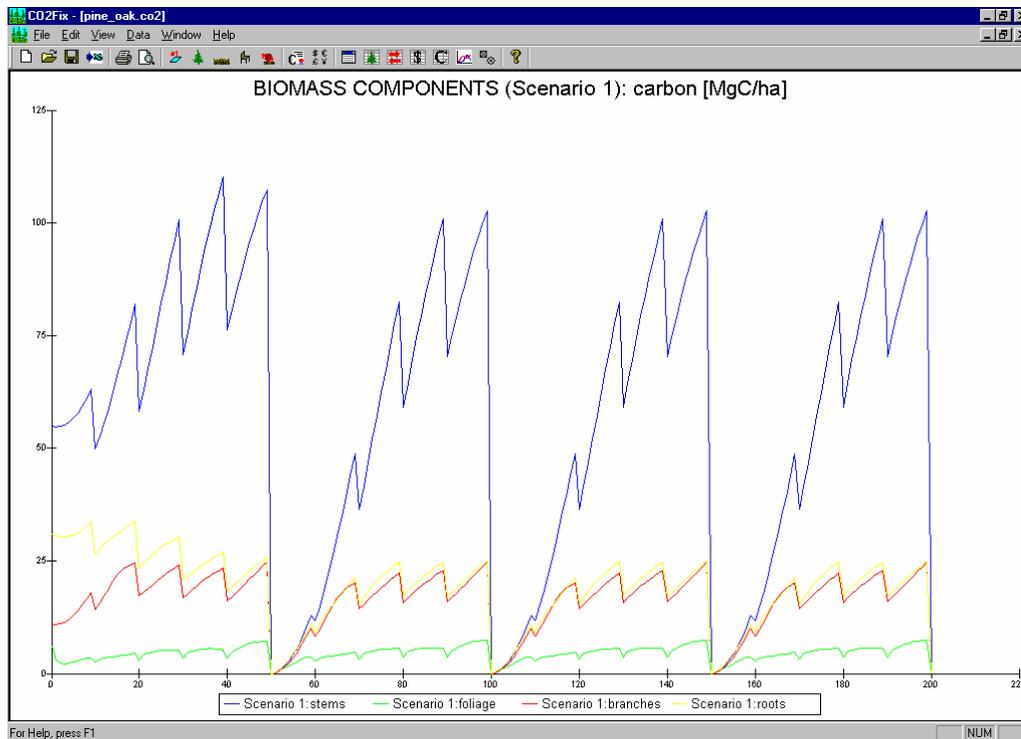
Figure 3.41. Example of a ready-made view option showing carbon stocks in each of the main carbon pools.
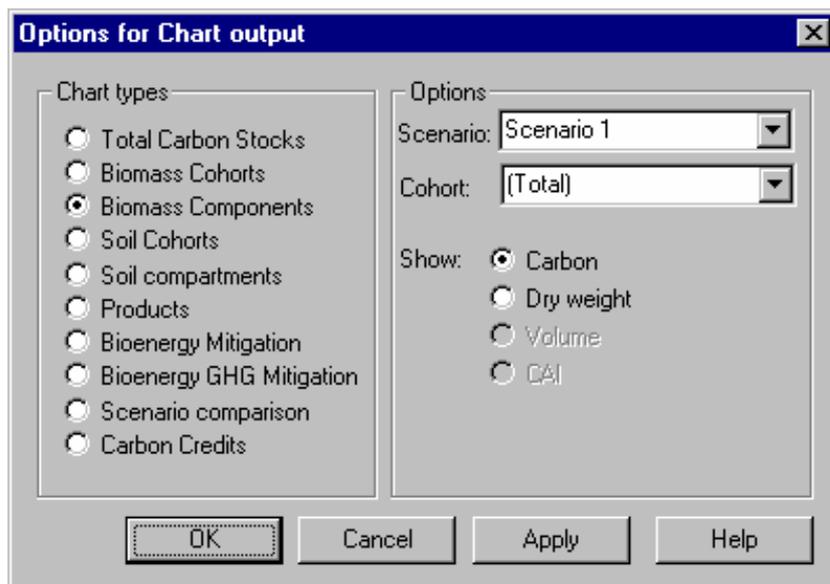
Figure 3.42. Options to change the content of the ready-made charts.

4 Example parameterisations

4.1 Introduction

Together with the CO2FIX V 3.1 model, a couple of example files are provided. These cases are parameterised by the CASFOR team and can serve the user as a basis for his own parameterisations and as an example how the different modules and options can be used. We have tried to include a range of examples that covers all aspects of the CO2FIX V 3.1 model and a range of different countries and regions as well. Table 4.1 gives a summary of the examples, indicating their location, tree species and modules and approaches used. In the following sections, each of these examples is discussed. For the first example a more extensive description is included, to show the parameterisation process step by step.

Table 4.1. Overview of the examples included

File name (.co2)	Country/ region	Tree species	Number of cohorts	Growth	Competition	Management mortality	Products	Bioenergy	Financial	Carbon crediting
NL_Scots pine X	Netherlands	Pinus sylvestris	1	A	-	-	X	-	X	-
Fin_Scots pine	Southern Finland	Pinus sylvestris	1	A	-	-	X	X	X	-
Fin_Norway spruce	Southern Finland	Picea abies	1	A	-	-	X	X	X	-
Rom_Robinia_affor	Romania	Robinia pseudoacacia	1	A	-	T	X	-	X	X
Central Europe_FM	Central Europe	Picea abies, Fagus sylvatica	2	A	C	T	-	-	X	X
Central America_CDM_RIL	Central America	Tropical species	4	B	T	C	-	-	X	X
Central America_CDM_affor	Central America	Tropical species	4	B	T	-	-	-	X	X
Central Mexico_pine_oak	Central Mexico	Pinus spp., Quercus spp.	2	A	T	T	X	X	-	-
CR_coffee_agroforestry	Costa Rica	Trees/ coffee	3	A	C	-	X	-	-	-
CR_teak_plantation	Costa Rica	Tectona grandis	1	A	T	-	X	-	-	-
Ind_dipt_primary forest_protected	Kalimantan, Indonesia	Tropical species	6	B	T	T	-	-	-	-
Ind_dipt_primary forest_logged	Kalimantan, Indonesia	Tropical species	6	B	T	T	-	-	-	-
Ind_dipt_secondary forest	Kalimantan, Indonesia	Tropical species	6	B	T	T	-	-	-	-

Growth: A = as a function of Age, B = as a function of Biomass
Competition: C = relative to each Cohort, T = relative to Total biomass
Management mortality: C= depends on which Cohort is harvest, T = depends on the Total volume harvested

4.2 Scots pine monocultures in The Netherlands

4.2.1 General

This example shows a range of regularly managed Scots pine stands of different growth classes in The Netherlands (files NL_Scots pine X.co2). Increment data are derived from yield tables (Jansen et al., 1996). Five growth classes are distinguished, based on the maximum mean annual increment (MAI) reached during a rotation. The growth classes range from 4 (lowest growth class) to 12 with intervals of 2. For each site class, a separate CO2FIX file is set up, containing one cohort of type 'conifers'. The simulation length is chosen as 100 years, analogue to the yield table. Growth is driven by age, and no mortality and competition are included, since this is supposed to be captured in the yield table.

4.2.2 Biomass

Stems
Firstly, the current annual increment as a function of age is entered into the Stems tab from the appropriate yield table. Carbon content is assumed to be 50% (0.5), a value commonly used, but this may be subject to variations. However, no detailed better information source was available. Wood density is set to 0.49 Mg per m^3 of wood. Initial carbon in living biomass is set to zero, since we simulate the stand from scratch.

Foliage, branches
Vaessen (2001) compiled a dataset with Scots pine biomass data from all over Europe and derived regressions of foliage, branches, stem and root biomass on breast height diameter of individual trees. We applied the resulting relationships to the yield table data to obtain individual tree biomass of these compartments. Multiplication with the stem number yielded estimates of total biomass in these compartments for 5 year intervals (Figure 4.1). Subsequently the allocation parameters for foliage and branches at various ages were set to 1 and changed by trial error to match as good as possible to the biomass curves (Figure 4.1). In order to do this, we first need the initial biomass, carbon content and the turnover coefficients. Initial biomass is set again as zero and carbon content at 0.5. For branch turnover we took a coefficient of 0.03, rather arbitrarily. For foliage, we know that in general two needle classes are present for Scots pine (Janssens et al., 1999; own observations), this year's needles and last year's needles. If we assume hypothetically that the same amount of foliage is produced each year, the total amount of foliage should be twice as much. Therefore we take a turnover coefficient of 0.5 for the foliage, since:

$$\lim_{x \to \infty} \sum 0.5^x = 2$$

The growth correction factor is set at 1, since we derive specific allocation curves for each growth class. Later on, these allocation curves could perhaps be combined to one general curve for Scots pine, which can be adjusted by the growth correction factor to correct for the specific growth class.
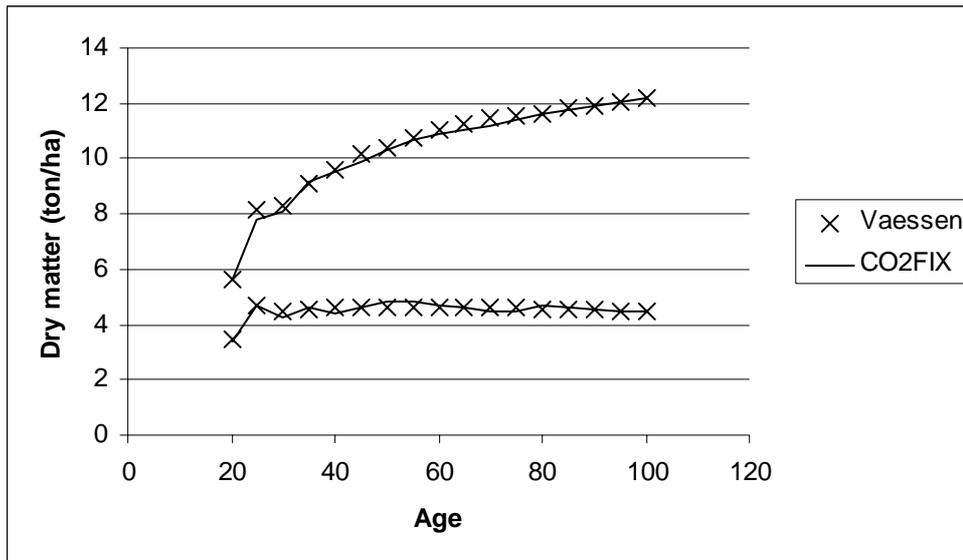
Figure 4.1. Total biomass per hectare in branches (upper line) and foliage (lower line) as derived from yield table data combined with the functions of Vaessen (2001), compared to CO2FIX simulation results for the same biomass compartments, for yield class 4.

Roots

In principle for the root compartment the same approach as for branches and foliage could be followed, but we used a more detailed approach, since more information was available. Rasse (2001) developed a general model for below-ground carbon allocation in temperate forests, based on root-shoot ratios found in literature. According to their results, the fraction of assimilates allocated to aboveground parts (AG_{frac}) as depending on age of the stand (in years) is as following:

$$AG_{frac} = 0.47 \times (1.0 - e^{-(2.0+age)/5.0})$$

The fraction of assimilates allocated to belowground parts (BG_{frac}) is then calculated as:

$$BG_{frac} = 1.0 - AG_{frac} - STA_{frac}$$

where STA_{frac} is the starch fraction used to restart leaf growth of deciduous trees in the spring. STAfrac for Scots pine is therefore set to 0.0, while for beech they suggest a value of 0.0 during the leaf shooting phase, and 0.1 during the rest of the growing season (they work with a much shorter timestep, depending on the timestep of available weather data). With these formulas we can calculate at any age the fractions of above- and belowground allocation, as well as their ratio. From the earlier derived parametrisation of foliage and branches, relative growth of foliage (F_f), branches (F_b) and stems ($F_s=1$) is known. The relative growth of roots (F_r) can then be expressed as:

$$F_r = \frac{BG_{frac}}{AG_{frac}} \times (1 + F_f + F_b)$$

Carbon content is again set at 0.5 and initial carbon at 0. The turnover coefficients is more difficult to determine: Rasse (2001) give a fine root turnover of 1 and a coarse root turnover of 0.02. However, CO2FIX does not distinguish between fine and coarse roots. Therefore we try to calculate an average turnover. However, young stands have a high proportion of fine roots and therefore a high turnover, whereas old stands have relatively much coarse roots and a correspondingly low turnover, so overall root turnover should decrease with time. From the output of CO2FIX we can determine how much carbon (in absolute quantity) is allocated to the stem and from our own calculations we know the relative growth rate of the roots at various ages. When we combine these, we can calculate for each year the absolute quantity of carbon allocated to the roots. According to Rasse (2001) during the leaf expansion phases in spring all below-ground assimiliates are allocated to the fine roots, while during the rest of the year 75% is allocated to fine roots and 25% to coarse roots. If we assume a three month period for the leaf expansion phase, on average 80% is allocated to fine roots. In a simple worksheet calculation we can allocate the total annual root assimilates to fine and coarse roots, and determine the annual absolute turnover with the abovementioned turnover rates. Then we can calculate a weighed average of turnover relative to the carbon stock in the roots over the full 100 year period, realising that this turnover will be too small in the beginning of the simulation and too large towards the end, leading to inaccuracies in the simulated stock in the root system and correspondingly in the litter input to the soil (see also De Bruijn, 2004).

Mortality, Management mortality and Competion are not parametrised, since this should be covered already in the yield tables.

Thinning-Harvest
According to the yield table, thinnings are carried out every five years. However, in practice the first thinnings are left out because they yield only unmarketable wood. Instead, a first thinning without yield of 1,000 trees per ha was assuemd to take place at an age of 20 tot 35 years, depending on the site conditions.

The thinning intensity (fraction removed) is calculated as the fraction of volume removed in a thinning relative to the sum of remaining volume and the removed volume. The minimum diameter for pulp- and paperwood is 8 cm (Heidemij, 1980; van Wijk, 1999), so we made sure to have 50% of the trees allocated to pulpwood at the age where the average diameter of the thinned trees exceeded 8 cm in the yield table. The minimum diameter for sawnwood is 20 cm at the smallest end (van Wijk, 1999). We assume here that a small portion (10%) of the stems will be suitable for sawnwood at the age where the average diameter exceeds 20 cm. Further, allocation over Logwood and Pulpwood is more or less linearly interpolated between these points, and an increasing fraction is allocated to Logwood after this last point. Losses (stemwood remaining in the forest) are assumed to be at least 10%.

4.2.3 Soil

Mean monthly temperature and precipitation are obtained from the website www.worldclimate.com, location De Bilt, for the period 1971-2000. The annual degree days are calculated to be 3439 °C and potential evapotranspiration 468 mm. Total precipitation in the months April-October is 460 mm.

From the flux output table we calculated the average carbon input to the soil for branches, foliage and fine roots. For the stems we need to consider only the part that is not harvested, which can be calculated from the parametrisation in the products tab (see later). We used these averages as input for the option 'Calculate initial carbon' to initialise the soil carbon. However, this will in this case probably lead to an overestimation of soil carbon, since a large part of the Scots pine stands in The Netherlands are planted on former driftsands and heathlands about 100 years ago, so they will still be accumulating carbon nowadays.

4.2.4 Products

For the products compartment we took the 'high processing and recycling efficiency' default as basis, with some changes. Overall the quality of Dutch Scots pine is not very good (Jansen, 1999), so we lowered the proportion of Logwood allocated to sawnwood to 35% and increased the fraction of boards to 45%. According to Heidemij (1980), half of the pulpwood production in 1976 was for paper, so we assume 45% for boards and 45% for paper, with 10% loss to firewood. Further, we lowered the amount of products ending up in landfills to 5%, since landfilling is not so common in The Netherlands. Most of the discarded products are being burned, so the fraction used for energy is increased accordingly.

4.2.5 Financial module

Recurring costs are derived from statistical data as derived from forest enterprises by Berger et al., (2003), and consist out of € 28 ha^{-1} yr^{-1} for levies, taxes and contributions, € 19 ha^{-1} yr^{-1} for infrastructure and € 43 ha^{-1} yr^{-1} for management and supervision.

Costs for silvicultural measures are derived from cost standards from the Dutch State Forestry Service (Staatsbosbeheer, 2000). The costs for stand establishment (4500 transplants per ha) are in total € 3593 per ha, consisting of € 502 per ha for ground preparation, € 194 per ha for unloading and storing planting material, € 1575 per ha for planting material and € 1322 for planting. The costs for the first (uncommercial) thinning are € 333 per ha.

Selection of quality trees takes place once every rotation and cost € 98 per ha. The costs for marking trees depend on the number of trees per ha to be marked, and amount up to € 165 per ha.

The costs for thinnings with yield and final cutting are based on cost standards for harvesters and forwarders. The cost for harvester operations depend on the tree

diameter and vary from € 5 to € 18 per m³. The costs for timber extraction using a forwarder are set to € 6 per m³, where as the cost for transportation of timber to the factory are set to € 5,50 per m³.

The returns at the factory (delivery value) for pulp logs are set to € 35 per m³, whereas the returns for saw logs are set to € 50 per m³.

4.3 Managed Scots pine and Norway spruce stands in Southern Finland

4.3.1 General

The examples of Scots pine (*Pinus sylvestris* at *Vaccinium* site type – Fin_Scots pine.co2) and Norway spruce (*Picea abies* at *Myrtillus* site type – Fin_Norway spruce.co2) stands in Southern Finland are based on the study of Kaipainen et al. (2004). Both stands contain only one cohort. The simulation length is 450 years with a rotation length of 90 years.

4.3.2 Biomass parameters:

Current annual increment (CAI) was taken from local growth and yield table (Koivisto, 1959) and dry wood density values were derived from the CO2FIX V 2.0 manual (Nabuurs et al., 2002, 0.490 for Scots pine and 0.440 for Norway spruce), Carbon content was assumed to be 50% for all biomass.
The growth of other biomass compartments, i.e. foliage, branches and roots, needs to be parameterised as relative to growth of the stem. We determined these relative growth values by first calculating the biomass of each compartment on the basis of biomass equations (Marklund, 1988) and yield tables (Koivisto, 1959), then calculating the periodic growth and comparing that to the periodic growth of the stem. Turnover rates of different biomass compartments are needed in model to calculate the litter production. We derived these turnover coefficients for foliage (0.25 for Scots pine and 0.16 for Norway spruce) from Kellomäki et al., 1992 and for branches (0.027 for both tree species) and roots (0.027 for both tree species) from Liski et al. (2002). Thinning regimes were taken from national guidelines for forest management (Metsätalouden kehittämiskeskus Tapio 2001) and no natural mortality, competition or management mortality was assumed in these examples.

4.3.3 Soil parameters:

General parameters for conifers were used in the soil module (Liski et al., 2003b, Karjalainen et al., 2002). Climate data (precipitation during the growing season, mm and potential evapotranspiration during the growing season, mm) were derived from a global climate dataset (www.worldclimate.com) using the climate data of Tampere, Finland. Degree days (above zero, °C) were calculated from the mean monthly

temperatures using the method described by Liski et al (2003b). Initial soil carbon stocks were calculated and added to the soil module on the basis of preparatory simulations, which were done to determine the mean annual carbon input to forest soil with each rotation length.

4.3.4   Wood product parameters:

Harvested wood is divided into logwood, pulpwood and harvest residues. We assumed that there is no logwood before the mean diameter exceeds 20 cm in the yield table; and if harvested roundwood has not yet met the requirements for logwood, 85% of the harvested wood goes to pulpwood and the rest to the soil as harvest residues. When the mean diameter has exceeded 20 cm, 30% of the harvested roundwood is allocated to logwood, 60% to pulpwood, and the rest to soil as harvest residues in thinnings, and in final fellings 60% is allocated to logwood and 30% to pulpwood. Product module parameters were defined separately for each tree species by slightly modifying the figures given in Karjalainen et al. (1994). Because of the large uncertainties related to landfill, it was excluded from our examinations.

4.3.5   Bioenergy parameters:

Input sources of fuelwood are harvest residues from the biomass module and raw material and process losses from products module. In our simulations, we assumed that 60% of harvest residues (from stem, branches and needles) from the final harvests of Norway spruce stands were utilised as energy. Harvest residues from thinnings and Scots pine stands were not utilised in these simulations. Industrial residues from both Norway spruce and Scots pine were assumed to be utilised as energy. In Finland the process waste of forest industries is actually the biggest domestic source of energy. Process losses were determined based on VTT Energy (1999) and Hakkila & Fredriksson (1996). 16% of raw material in sawn wood was allocated to boards, 20% to paper and 15% to energy. 30% of raw material in boards was allocated to papers and 19% to energy and 40 % of papers were allocated to energy.

Default values of general parameters (heating values of fuelwood and global warming potentials of gases) and emissions of different fuels and technologies were used. Slash fuelwood, meaning harvest residues of the final harvests of Norway spruce, were assumed to be burned in combustion plant smaller than 50 MW and substitute coal burned in power plant. Industrial residues from all the processes from both Norway spruce and Scots pine were assumed to be burned in combustion plant bigger than 50 MW and substitute coal burned in power plant. Applicability of the default emission values to Finnish energy production systems was not evaluated.

4.3.6   Finance parameters:

Cost and revenues of the forest management were derived from Finnish Statistical Yearbook of Forestry 2001 (FFRI, 2002). Costs were as follows: soil preparation (harrowing and scarification) 144.14 €/ha, Planting 737.83 €/ha and tending of seedlings 221.12 €/ha. Stumpage of pulp logs was parameterised to be 25.13 €/m^3 and stumpage of saw logs 48.32 €/m^3.

4.4   Afforestation in Romania

The file Rom_Robinia_afforestation.co2 contains a monoculture of Robinia (*Robinia pseudoaccacia*) on degraded soils in Romania that were formerly used for agriculture. This case is based on a small part of a larger real life afforestation project that is currently carried out in Romania (Brown et al., 2002). Figures and practices in this parameterisation were followed as good as possible. However, the real life case has a project duration of 30 years, but here a total project life of 60 years is assumed. This was done to facilitate the comparison with the next three cases, as described in Groen et al. (In prep.) A mortality of 2% per year is assumed for the first 10 years, which decreases after 10 years to 1%. No logging related mortality was assumed. Products are excluded from the carbon calculations. An initial soil carbon content of 54 Mg C ha^{-1} was assumed (Brown et al., 2002). Because this is a JI project (carbon credits are purchased by the prototype carbon fund) a base line is required. Degrading grassland is simulated in the CO2FIX program serving as a base line with an NPP of 9 Mg DM ha^{-1} y^{-1} at the beginning, declining to 5.9 Mg DM ha^{-1} y^{-1} at the end of the simulation after 200 years. 60% of the grass is harvested every year by grazing and turnover rates are 0.8 for foliage and 0.9 for roots. Costs and benefits are based on original project literature, but may deviate from the real life case due to interpolation from project scale costs to hectare scale costs and possible omissions of costs (Brown et al., 2002). Because wood is sold as stumpage, no harvesting costs are calculated. For soil weather data the site 'Bucharest' was used from http://www.worldclimate.com.

4.5   Forest Management in Central Europe

The file Central Europe_FM.co2 is based on a case presented earlier by Nabuurs and Mohren (1993) and Masera et al. (2003) that dealt with an even aged monoculture of Norway spruce (*Picea abies* L. Karst.) on a fertile site in the middle mountain regions in Central Europe. This case is now extended with 'forest management', i.e. it is assumed that through management, the increment has increased and that instead of a clearcut after 95 years, regeneration of beech (Fagus sylvatica) is stimulated when Norway spruce has reached an age of 45 years, resulting in a mixed stand of Norway spruce and beech. Selective logging is applied in this stand.

The harvesting regime of the spruce cohort is adjusted. The initial non-commercial thinning of 20% and the 3 follow up thinnings of 20% remain. However, no final

logging is carried out, but 4 follow up thinnings of 15% of standing biomass follow until the year 200. The beech cohort is also thinned at year 140 with 20% and at year 200 with 30%. Products are excluded from the carbon calculations. Because it is a regular forest management project, no baseline is needed. Previous land use was assumed to be Norway spruce as well: thus the soil was initialised with 90 Mg C ha^{-1}, of which 10 Mg C coarse woody litter from logging slash. For soil weather data site Freiburg was used from http://www.worldclimate.com.

4.6 Reduced impact logging (RIL)

The file Central America_CDM_RIL.co2 contains a CDM case for a lowland wet tropical rainforest in Central America. The baseline situation is conventional (heavy) logging followed by further degradation. This type of management is not eligible under the CDM yet, but may be accepted in the future. Four cohorts are distinguished: 1) Traditionally commercial species; 2) Potentially commercial species, 3) Other species; 4) Pioneers. Cohorts 1, 2 and 3 used to be harvested at a 20-year cutting cycle. Growth in this forest is not specified in relation to age, but in relation to standing biomass (Masera et al., 2003). Competition is important, and has a profound impact on the pioneer species in the forest (Masera et al., 2003).
On average a higher roadside price for wood from the RIL project can be expected ($ 200 vs 160/m3) because less wood is damaged. However, in case of RIL, there is a loss due to missed logging revenues. We work with rather high harvesting costs here, because roadside prices are used. No other costs or returns are expected. The soil carbon was initialised with a stock of 111 Mg C ha^{-1}. For soil weather data the site San Jose, Costa Rica was used from http://www.worldclimate.com.

4.7 Afforestation under the Clean Development Mechanism (CDM afforestation).

The file Central_America_CDM_afforestation.co2 deals with the afforestation of an area in Central America that is currently used as a pasture. Initial grass NPP is 10 Mg dry matter ha^{-1} yr^{-1}. The site is degrading due to overgrazing, reduced litter input to the soil, and subsequent loss of soil organic matter. The soil is initialised with 58 Mg C ha^{-1}.
The project scenario assumes an active reforestation with native species in four functional groups: 1) Traditionally commercial species; 2) Potentially commercial species, 3) Other species, and 4) Pioneers. Growth data are from Camacho and Finegan (1997) and provide an NPP of around 4 to 5.5 Mg C NPP at its maximum. No harvesting is carried out, the forest is left to its natural dynamics with some 2 to 3% natural mortality per year. The same growth rates are applied as in the CDM—RIL case. Costs data are from Boer (2001), and are estimated at $400 for initial establishment (in a landscape level scheme) and at $44 recurring annually.

4.8   Pine-Oak Central Mexico

The file Central Mexico_pine_oak.co2 is an example of an unevenaged mixed stand of Pine (Pinus spp.) and Oak (Quercus spp.), characteristic of the highlands of Central Mexico. A more extensive description can be found in de Jong et al (In prep.). The region has volcanic soils of varying depth and fertility. Increment data are derived from yield tables, obtained from the forest inventory of Nuevo San Juan Parangaricutiro (DTF-CINSJP, 1998).

The baseline scenario (named conventional scenario) shows the typical management regime of mixed pine-oak forests, as been recommended by the Mexican government. The management is based on a 50 yr rotation cycle, with thinnings every 10 years. Pine trees are subject to logging, with 80% of the volume removed at the end of the 50-year cycle. About 30-40 trees per ha will remain for 10 years, in order to propagate natural regeneration. Competing oaks are removed every 10 years (about 30% of standing volume) and completely removed at the end of the rotation cycle.

Competition is simulated based on total standing biomass. A mid to low efficient processing and low recycling of wood products has been assumed. Soil carbon simulation is still preliminary, and has been simulated using precipitation and evapotranspiration of the dry season.

In the Oak conservation scenario all parameters are the same as in the baseline scenario, except that the oak removal is reduced. Only 20% of the highly competing oaks are removed at each thinning or harvesting activity.

The Oak conservation-Bioenergy scenario is similar to the Oak Conservation scenario, except that a large fraction of the harvested product and slash is used to generate bio-energy to substitute fossil fuels.

4.9   Teak plantation Costa Rica

The file CR_teak_plantation.co2 contains an example of a Teak (Tectona grandis) plantation in Costa Rica on a degraded soil. The mean annual increment (MAI) is 15 m^3 ha^{-1} yr^{-1} over the rotation of 40 years. Thinning takes place at ages 3, 10, 20, and 30 years. Financial information is derived from Puolakka (2003).

4.10   Agroforestry, Costa Rica

The file CR_coffee_agroforestry.co2 contains an example of an agroforestry system in Costa Rica. The system contains three cohorts. The canopy layer consists of shade trees of the species Cordia alliodora (100 trees per ha), with a rotation of 20 years. The wood is used for furniture. The intermediate layer consists of Erythrina poeppigiana, which is a service tree. It is managed in a 10-year rotation, and each year leaves and branches are pruned and left to decompose. The understory consists of

Coffea species, which are renewed every 20 years. Most data are obtained from Fassbender (1993).

4.11 Lowland dipterocarp forests at Kalimantan, Indonesia

4.11.1 General

For an application of the landscape level model CO2Land in Kalimantan, de Bruijn (In prep.) set up a series of files covering a range of different landuses. Three of those are included with the CO2FIX V 3.1 installation, showing three cases of lowland dipterocarp forests at Kalimantan, Indonesia: protected primary forest (Ind_dipt_primary forest_protected.co2), logged primary forest (Ind_dipt_primary forest_logged.co2) and secondary forest (Ind_dipt_secondary forest.co2). Data were obtained from the Malinau Research Forest, supplemented with literature data. The generally 150-250 tree species per hectare of undisturbed forest were categorised in 6 cohorts according to common growth characteristics (Philips et al., 2000, Soerianegara, et al., 1993; Sosej et al., 1998) and common use of the different tree species.

4.11.2 Protected primary forest

For the initial situation, dry weight biomass of the stems was estimated from sample plot recordings, using an empirical equation by Brown et al. (1989). Data from Yamakura et al. (1986) were used to estimate initial biomass of branches and leaves. Initial root biomass was taken as 17% of total stand biomass (Pinard & Putz, 1996). Stemwood densities were derived from http://www.worldagroforestrycentre.org/sea/Products/AFDbases/WD/, carbon content for all biomass components was assumed to be 0.5.

In the sample files, stem increment is depending on the total biomass of the stand. Increment was estimated from re-measurements of the permanent sample plots. Maximum increment was derived from plots with low biomass densities. Competition was set by trial and error to suppress the increment at higher biomass densities. Relative increment rates of other biomass components were balanced against the turnover and matched with data from Yamakura et al (1996). Natural tree mortality was set at 1% according to Bertauld & Kadir (1998). Turnover rates for the tree components are frequently fairly unknown or unspecific. In this study, foliage turnover was set at 1 yr^{-1} according to Kira & Shidei (1967). They suggest even higher foliage turnover for tropical moist forests (1.3 – 1.5 yr^{-1}), but CO2FIX V 3.1 does not allow foliage turnover values over 1 yr^{-1}. Branches turnover was set at 0.10 yr^{-1}, according to Kira & Shidei (1967) and root turnover was set at 0.10 yr^{-1} according to Gill and Jackson (2000).

Degree-days for the soil module was obtained by multiplication of the average temperature (estimated at 26ºC, Bertault & Kadir, 1998) with a 365 days growing

season. Precipitation in the growing season was set at 3789 mm according to ITTO (2002). Potential evapotranspiration in the growing season was estimated at 1500 mm. Default Yasso model parameters are used. The initial carbon quantities for the different tree components were estimated assuming a constant input of the different biomass components, which were estimated by multiplication of the turnover coefficient with the estimations of initial carbon in the different tree components.

4.11.3 Logged primary forest

If logging impact is low and does not change the forest structure and composition too much, forests can still be regarded as primary forest. To simulate this, the primary forest example is harvested in a 35-year cycle, followed by management mortality. From the sample plots, an average harvested volume of 40 m^3 ha^{-1} was estimated. Management mortality was implemented using the figures suggested by Bertauld & Kadir (1989), who suggest tree mortality increases after harvest from 1.5% yr^{-1} to 2.5% yr^{-1}, lasting for 15 years.

4.11.4 Secondary forest

If the forest structure and species composition have changed significantly from the primary situation, a forest will be classified as secondary. The causes can be diverse, such as logging, fire and re-growth after cultivation. This example simulates a forest which is degraded due to heavy logging. For the simulation, the same cohorts as in the primary forest were used. Total initial biomass is set at 50% of the untouched situation, with a 15% share for the pioneer species after the suggestion by Mori (1999). Because of the lack of commercial species, this forest is not logged anymore.

5 Special parameterisations

5.1 Introduction

Although CO2FIX was originally developed for forest ecosystems, questions arose if it could be applied to other systems as well. With the development of CO2Land, this question became even more important. Moreover, there was interest in the simulation of coppice systems (e.g. Lettens et al., 2003), disturbance events and climate change. In this chapter we will show some examples of the use of CO2FIX for other purposes. These examples are provided with the model and can be found in the directory 'Special Cases'.

5.2 Non-forest systems

The CO2FIX model is in the first place meant to be used for assessment of forest ecosystem carbon balances. However, it is possible to parameterise CO2FIX in such a way that it represents grassland or cropland systems. However, when doing this, the user should keep in mind that the model was never really designed to be used for grass or cropland ecosystems. An example of a simulation of a grass ecosystem is shown in the file grass.co2 in the directory 'Special Cases'.

In order to simulate a grass (or crop), the grass can be seen as a 'tree' with a very small stem volume, no branches and a lot of foliage and roots. The stem part is needed, since allocation to foliage and roots is driven by stem increment. In order to keep the influence of the stem compartment as small as possible, a very small increment has to be specified, for example 0.01 (Figure 5.1). The foliage and root compartment receive a very high relative increment, 500 and 400 respectively (Figure 5.1). Since the wood density has been set at '1', the aboveground production is $500*1*0.01 = 5$ Mg DM ha^{-1}. Similarly, belowground production is 4 Mg DM ha^{-1}. Characteristic for grassland systems are the high turnover rates in foliage and roots, in this case set at 0.8 and 0.9 respectively. To avoid a large build up of biomass in the stem, a high mortality rate (0.9) is parameterised as well. If the grassland is managed, harvest can be inserted as well. However, the user should be careful here. An annual harvest of 60% means that 60% of the stem biomass is removed, but foliage will be regarded as slash. Therefore, the Slash Fire Wood box should be set at 1, to indicate that all slash is removed. This is shown in the scenario 'Grassland managed'.

As a guideline, Table 5.1 shows some production estimates of grassland and pasture systems around the world.
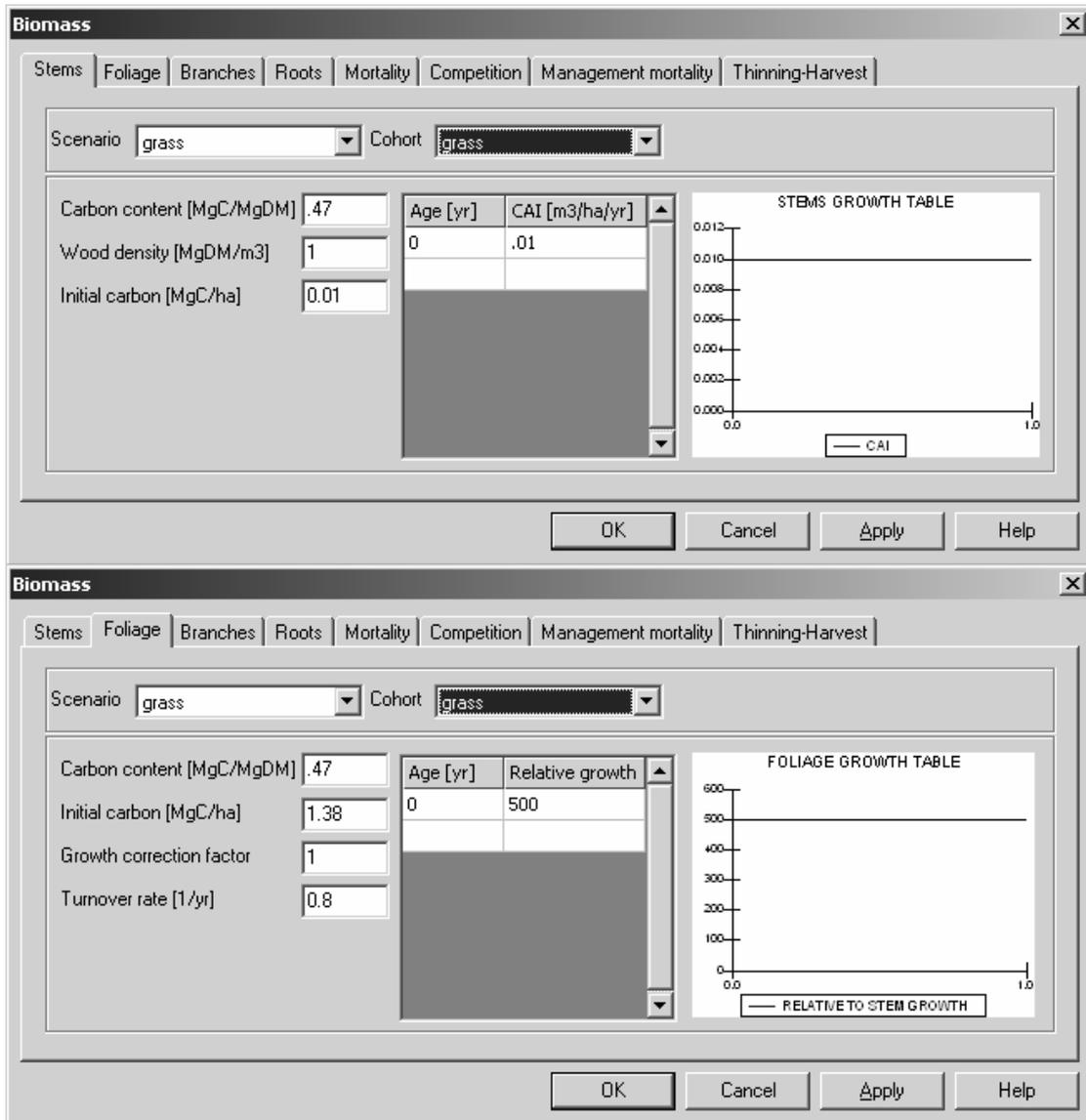
Figure 5.1. Suggested parameterisation for grassland, showing the stem and foliage compartment. Roots compartment is similar to foliage.

Table 5.1. Production of grassland and pastures in different regions of the world

Type	Region	Source	Production (Mg DM ha^{-1} yr^{-1}) Aboveground	Belowground
Cold desert steppe		Parton et al., 1995	0.6	0.92
Temperate steppe		Parton et al., 1995	0.36	0.59
Short grass steppe	central great plain, USA	Campbell et al., 2000	0.5-3	
Dry savanna		Parton et al., 1995	0.55	0.85
Semi arid savanna	Sahel	Campbell et al., 2000	0.5-2.5	
Savanna		Parton et al., 1995	1.91	2.22
Tropical savanna woodland	Australia	Campbell et al., 2000	2	
Subtropical savanna	Australia	Campbell et al., 2000	2.5	
Humid savanna		Parton et al., 1995	3.4	3.44
Mediterranean grassland		Parton et al., 1995	0.79	1.03
Semi arid grassland	inner Mongolia	Campbell et al., 2000	1.2-2.6	
Savanna grassland	N-Australia	Campbell et al., 2000	0.5-3	
Temperate grassland	Australia	Campbell et al., 2000	0.5-4	
Tall grass prairie	Kansas, USA	Campbell et al., 2000	3.95	
Grassland	Switzerland	Campbell et al., 2000	6.5-12	
Pasture	Mediterranean Europe	Vleeshouwers and Verhagen, 2002	3.5-8	
Pasture	Central Europe	Vleeshouwers and Verhagen, 2002	4-9	
Temperate pasture	Australia	Campbell et al., 2000	5-10	
Pasture	New Zealand	Campbell et al., 2000	6-8	
Pasture	Northern Europe	Vleeshouwers and Verhagen, 2002	6-11	
Pasture	Western Europe	Vleeshouwers and Verhagen, 2002	8-14	

5.3 Coppice

The CO2FIX model was originally not designed for simulating coppice systems. However, with some additional work, it is possible to simulate such systems. This example is illustrated in the file coppice.co2 in the 'Special Cases' directory. The simulated system is a coppice system of Eucalyptus globulus in Galicia, Spain. Data for the first rotation are based on the work of Valero and Picos (Valero and Picos, 2002; Valero and Picos in prep). In a coppice system, all aboveground biomass is removed with a certain interval, depending on the tree species and the aim of the product, after which the trunks will re-sprout. This interval can range from a few years to several decennia, in this case 16 years. The fraction of removed trees must be 1 to simulate the harvest of all aboveground biomass. The allocation of the removed trees to logwood or pulpwood depends on the purpose of the coppice system. In the case of coppice, most branches are harvested as well, which is taken into account by entering a fraction in the Branches to Logwood or Branches to Pulpwood cells. If the aim of the coppice system is to generate energy, all stems and branches can be allocated to Slash, and a 1 can be put in the SlashFireWood cell, indicating that all

slash (stems plus branches plus foliage) is used as firewood. The parameterisation of the stem increment and allocation to other biomass compartments will be different for coppice than for high forest, especially after coppicing, and thus needs special attention.

As far as the aboveground biomass and products is concerned, this method will work well. However if a thinning is carried out in CO2FIX, the root compartment will loose the same fraction of roots as the fraction of trees that is removed. So in this case, all roots will die when all aboveground biomass is harvested, while in reality the root system will stay alive. In the model this causes extra input to the litter, with repercussions on the simulated carbon stocks in the soil. A way to solve this problem is to make separate simulations, one for the aboveground biomass and products as described above, and separate ones for each rotation to simulate the belowground carbon and soil dynamics. The starting point for the simulation is the aboveground run. At the moment of harvest, the user can check the carbon amounts in the roots and all soil compartments. These amounts are then entered into a new simulation (see scenario 'below and soil 1'), so the root system is in place, but there is no initial aboveground biomass. The allocation pattern to the roots probably needs to be adjusted, because the root system is still intact. The annual increment for the second rotation may have to be adjusted as well, since the increment in the second rotation is often higher. At each harvest, the amounts of carbon in roots and soil should be used as initial values for a new simulation. Combined with the aboveground and products simulation from the first simulation, this will yield a full carbon cycle.

5.4   Fire

The following example deals with the case of forest fire. The example is illustrated in the file fire.co2 in the 'Special Cases' directory. Basis for this example is the Scots pine case in The Netherlands, yield class 8, as explained in Chapter 4. It is included in the scenario 'Regular' as comparison to the fire parameterisation.

Fire can be simulated in CO2FIX as a kind of thinning (using the thinning-harvest tab in the biomass module). The intensity of the fire can be expressed as the fraction of trees that is 'removed' (i.e. killed). If the fire is not too severe, part of the trees are killed, but still usable. This can be simulated by allocating a fraction of the trees killed to LogWood and/or PulpPap. Usually the wood is of lower quality, which can be expressed by a relatively high fraction of pulpwood. In our example, at year 72 a fire occurs that kills half of the trees. Of those trees, 20% is harvested and used as pulp or paper wood (Figure 5.2).

Biomass ✕

Stems | Foliage | Branches | Roots | Mortality | Competition | Management mortality | Thinning-Harvest

Scenario [Fire (biomass/products) ▼] Cohort [Scots pine ▼]   Rotation length [yr] [90]

Age [yr]	Fraction Removed	Stems LogWood	Stems PulpPap	Stems Slash	Branches LogWood	Branches PulpPap	Branches Slash	Foliage Slash	Slash FireWood	Slash Soil
60	.10	.1	.8	0.10	0	0	1.00	1.00	0	1.00
65	.08	.1	.8	0.10	0	0	1.00	1.00	0	1.00
70	.07	.1	.8	0.10	0	0	1.00	1.00	0	1.00
72	.5	0	.2	0.80	0	0	1.00	1.00	0	1.00
90	1	.2	.6	0.20	0	0	1.00	1.00	0	1.00

OK | Cancel | Apply | Help

Figure 5.2: Parameterisation of fire in year 72 that kills 50% of the trees.

The rest of the affected trees and all other slash will be added to the litter pools, which is of course not according to reality. In order to simulate this properly, we can make a new simulation, starting at the moment of the fire (cohort age at start of 72 years). As initial situation we take the biomass values from the first simulation just after the fire. We also take the carbon amounts in all soil compartments, but here we can adjust for the litter that is burned. In the example, we assume that all non woody litter and fine litter is burned, and around 30% of the coarse litter (i.e. 30 Mg C initially in the coarse litter compartment, opposed to 45.61 in the simulation just after the fire). The other compartments are not affected (See Figure 5.3). The soil module does not take into account any other effects of fire that may occur, like the formation of charcoal with very long lifetimes, emissions of CH_4 and volatile organic carbons, or other changes that might affect decomposition.
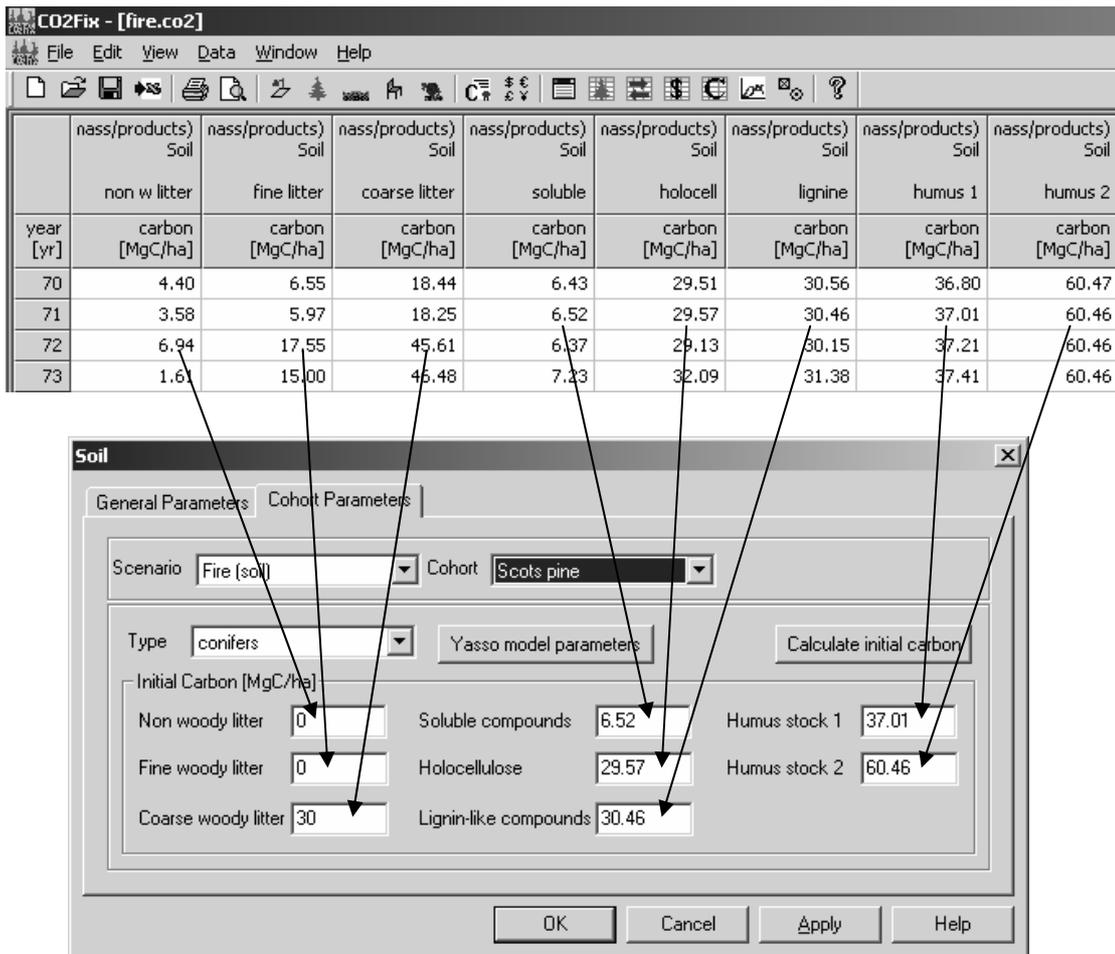
Figure 5.3. Initialisation of the soil module after the fire, assuming that 30% of coarse litter has burned as well as all fine and non woody litter.

Due to damage to the trees, increased mortality may occur in the years after a fire event. To simulate this, we can use the mortality tab of the biomass module (see for an example Figure 5.4). As a consequence of the reduced stocking and damage to the trees, in the example the increment is reduced in the period after the fire. Also the management has changed, all regular thinnings have been cancelled, and the final felling is carried out already at year 90.
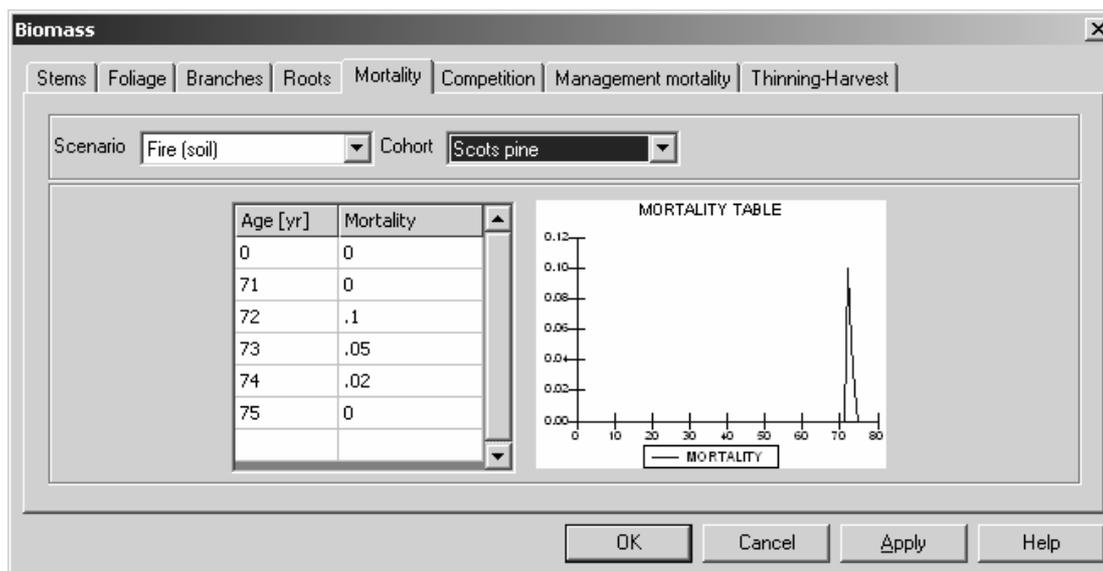
Figure 5.4: Parameterisation of increased mortality after the fire in year 72.

In the fire example, we now have two simulations, one with the right output for the biomass and the products over the whole simulation, and one that simulates the soil compartment after the fire. In order to obtain a full carbon balance, the user should combine the results of these two simulations. The results of the biomass compartment should be the same, but we need to continue the first simulation to keep track of the carbon in the products, since the product pools cannot be initialised in the model.

5.5   Storm damage

The following example deals with the case of storm damage. The example is illustrated in the file storm.co2 in the 'Special Cases' directory. Basis for this example is again the Scots pine case in The Netherlands, yield class 8, as explained in Chapter 4. It is included in the scenario 'Regular' as comparison to the storm damage parameterisation.

Storm damage can be simulated in a similar way as a fire, expressing the intensity of damage via the Harvest tab. The example shows a storm damage in year 81 which uprooted or broke 30% of the trees (Figure 5.5). The amount of wood salvaged can be simulated by specifying fractions of stems extracted for sawnwood or pulpwood. If the wood is damaged, a higher fraction of wood will be left in the forest or a higher fraction of pulpwood may be specified than in case of regular thinnings. In the example, only 10% of the downed wood is still usable as logwood, 50% is used for pulp or paper and 40% is left in the forest to decompose. Also after a storm increased mortality can occur, for example due to new windfalls at newly created edges or sunburn of newly exposed trees. These can be simulated in the same way as mortality after a fire (see for example Figure 5.4). Effects on the increment can be simulated similarly to the fire case. In the storm example, no effects on the increment

are assumed. The thinning at year 85 is cancelled, but further no effects on the regular management are assumed. Fire or storm damage might also be connected with higher costs, for example higher harvesting costs due to dangerous situations or costs for fire fighting. These can be specified in the financial module.
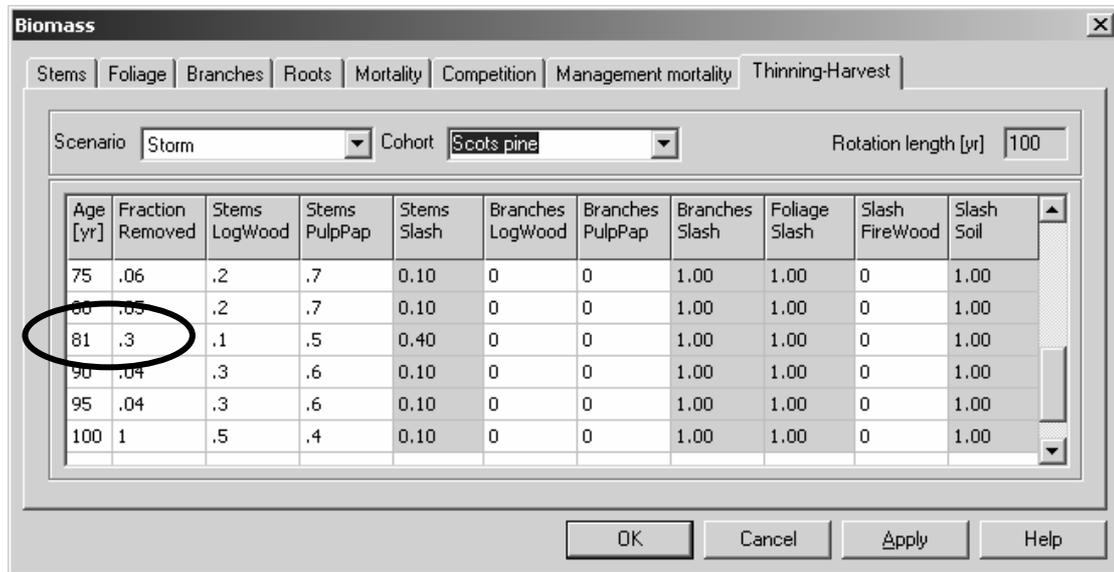
Figure 5.5: Parameterisation of storm damage in year 81 that uprooted or broke 30% of the stems .

5.6   Pests and diseases

Pests and diseases can cause damage to leaves, branches and roots or can even cause mortality. In this example, we discuss two cases: an outbreak of insects that feed on the foliage, and an outbreak of bark beetles. The example file is called pests.co2. Again we take the Scots pine 8 as a basis.

In CO2FIX a pest affecting the foliage can be simulated by adjusting the foliage allocation. In reality, the tree will make foliage, which is then eaten by the insects. However, in CO2FIX it is not possible to remove the foliage directly (at least not in one simulation). However, it is possible to decrease the allocation to foliage to simulate a reduced amount of biomass in a certain period. In the example (scenario 'Foliage feeder') a foliage feeding insect occurs at year 41 and 42, simulated by a zero allocation to foliage (Figure 5.6). Some mortality occurs during and afterwards of the defoliation, analogue to the fire case (see Figure 5.4). Also the increment is affected (Figure 5.7). Pests affecting branches or roots could be simulated in a similar way by adapting their respective allocation figures. A more realistic way to simulate defoliation would be to initialise a new simulation at the moment of defoliation and reducing the amount of foliage biomass as needed. The fine litter component should then be increased to simulate increased litter fall and excrements of the insects. However, this will have only minor effects on the total simulated carbon stocks in the soil.
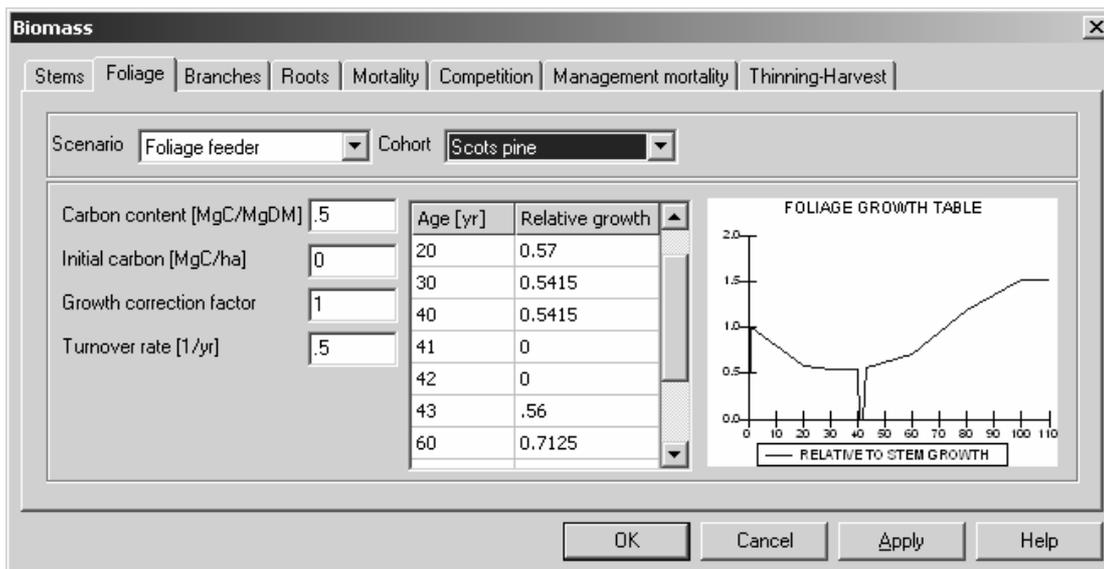
Figure 5.6. Parameterisation of a foliage feeding insect at year 41 and 42.
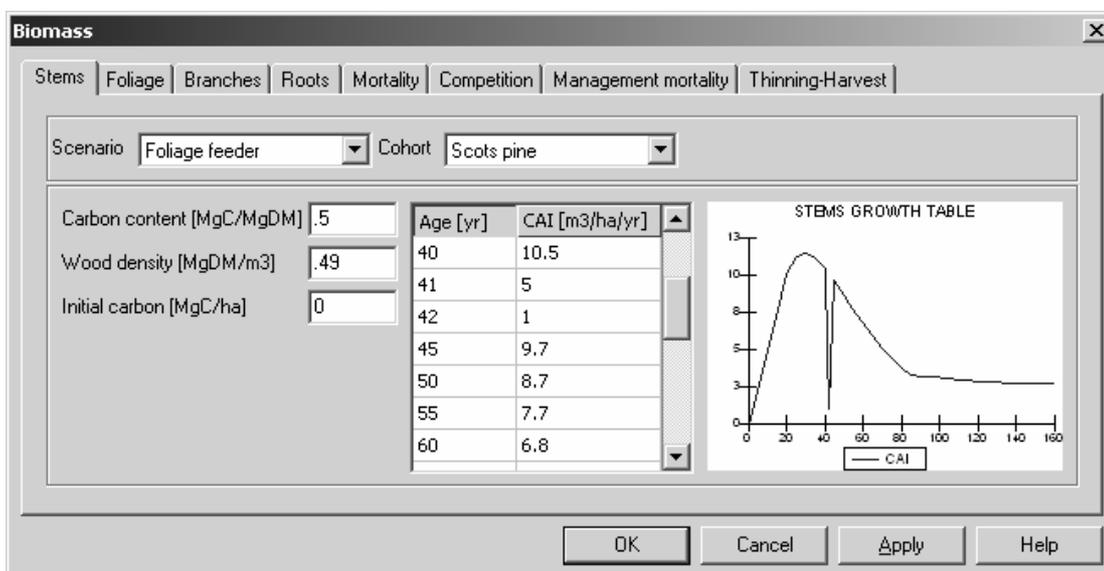
Figure 5.7. Reduced increment between 41 and 45 years caused by defoliation.

Insect pests causing direct mortality to the trees, such as bark beetles, can be simulated by a thinning in the same way as storm damage. In the example (scenario 'Bark beetles'), a five-year outbreak of bark beetles is simulated (Figure 5.8). This leads to a decreased increment during and after the outbreak (not shown). Specific costs for chemical or biological measures against the pest or disease can be specified in the financial module.
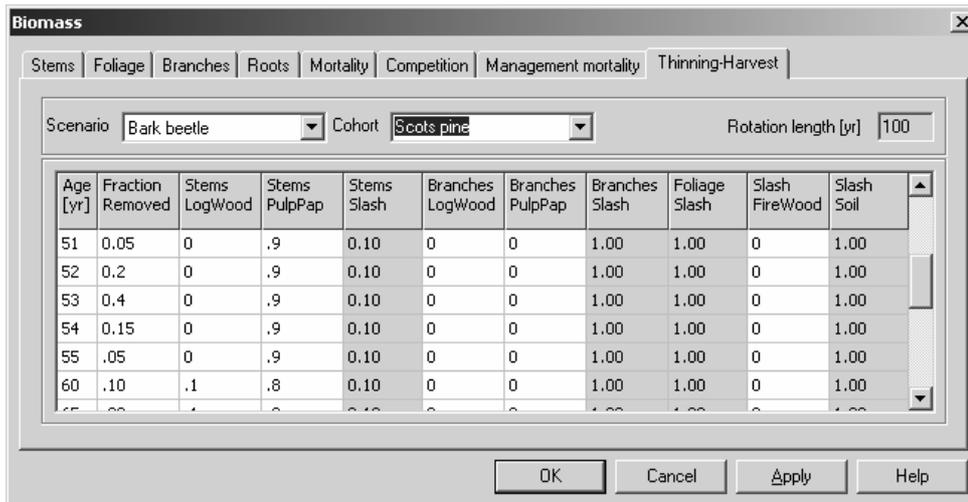
Figure 5.8. *Bark beetle outbreak causing mortality in years 51-55.*

5.7 Climatic change

Climatic change can have several impacts on the forest via different mechanisms, such as higher increments due to CO_2-fertilisation, higher temperatures and a longer growing season and lower increments due to decreased precipitation and increased evapotranspiration. Also the soil compartment may be affected by changes in temperature and water availability. In CO2FIX, the resulting changes can be simulated, but not its underlying processes. In our example (climatic change.co2), we show how climatic change could affect the Finnish Scots pine case. The process-based model FINNFOR was applied to a Scots pine stand in Southern Finland (Kramer and Mohren, 2001) for current climate and climate change conditions. The ratio between increment under current climate and climate change per age class is used in CO2FIX to express the effect of a changing climate on the increment (Figure 5.9). We assumed that allocation and turnover patterns are not affected. Changes in temperature, precipitation and potential evapotranspiration were derived from the GCM runs that were used as input for the FINNFOR model.
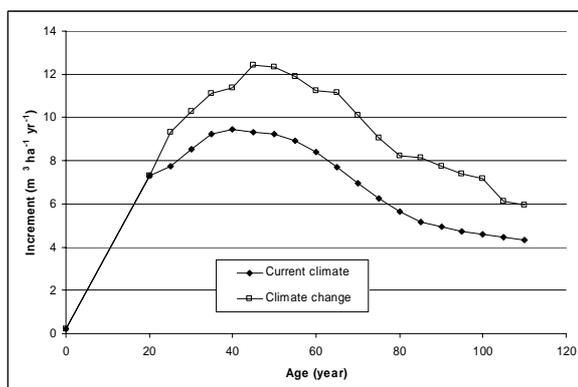
Figure 5.9. *Increment under current climate and under climatic change in the CO2FIX example for Scots pine in Southern Finland (Kramer and Mohren, 2001).*

6 Accuracy of the carbon balances as simulated by CO2FIX V 3.1

Errors in forest resource projections (and thus C balances) have two main sources (Kangas, 1997): a. the stochastic character of the estimated model coefficients; b. measurement errors in the data or lack of data used for model construction; Re a. In nature, an enormous variability occurs. This variability still exists within one clearly defined forest type and is the result of e.g. growth variation between years caused by weather circumstances, intra-species genetic differences, and site quality variation. This natural variability is not captured by CO2FIX because it very much relies on fixed input data from yield tables that can be seen as some sort of complete, and perfectly managed forests. Other stochastic events are management irregularity and risks caused by e.g. storm and fire. These events are not captured either, but can be parametrised as special cases (see Chapter 5). Furthermore natural variability occurs in carbon content of dry matter, basic wood density, litter and humus decomposition rates.

When parametrising CO2FIX this variability is usually dealt with by trying to find the average or median value of a parameter. Only when multiple runs are carried out in which the natural variability in e.g. growth rates, carbon content, and humus decomposition is captured, then CO2FIX provides insight in this type of uncertainty.

Re b. CO2FIX relies heavily on net annual increment data from yield tables. These tables are based on long-term measurement series in permanent plots and/or forest inventories. In these measurement series, errors and/or bias can occur. However these errors are usually very small. Both forest inventories and yield tables are generally seen as very reliable. Tomppo (1996) gives standard errors of some characteristics of the National Forest Inventory in Finland: forest land area 0.4%, growing stock 0.7%, and increment 1.1%. However, where input data for CO2FIX rely on few measurements or a single series, uncertainty in the predictions will increase very much. This type of uncertainty especially exists in the soil pools.

Van der Voet (in: Nabuurs & Mohren, 1993) carried out an uncertainty analysis of CO2FIX V 1.0. He specified input uncertainties in the form of simultaneous input distributions for an even-aged forest type. The 100 simulations with randomly chosen values of input gave an average total carbon stock of 316 Mg C ha^{-1}. The standard deviation was 12% and the 95% confidence interval was 254 - 403 Mg C ha^{-1}. He concluded that it was mainly the litter and humus coefficients and the carbon content that determined this uncertainty, but in general it was mainly the natural variability rather than a lack of data that determined the overall uncertainty.

Knippers et al. (In prep) carried out a sensitivity and uncertainty analysis of an early version of CO2FIX V 3.0. For 37 input parameters in the biomass, soil and products modules a standard deviation could be specified. When running the model, random values were taken for these input parameters, assuming a normal distribution. For the

sensitivity analysis all parameters were changed separately to analyse the effects on the outcomes. For the uncertainty analysis, all parameters were randomly drawn to determine the overall effect on the outcome. As an illustration of the sensitivity analysis, Figure 6.1 shows the results for the carbon content of the stems, with an assumed standard deviation of 5, 10 and 20% of the average. For the 20% standard deviation, the average total carbon stock was 186.4 Mg C/ha, with a 95% confidence interval of 155.5 - 217.3 Mg C/ha. So a 20% standard deviation in the input of carbon content of stems results in a 10% standard deviation in the total carbon stock per hectare. Generally the outcomes of the model were most sensitive to all parameters related to the stem compartment. This can be explained by two reasons. Firstly, the stem compartment represents one of the largest stocks in the whole system. Secondly, growth of the other biomass compartments is derived from stem increment, and all other compartments are depending on the outcomes of the biomass module. So a change in one of the stem parameters influences the results of all other calculations. Further, the model proved to be sensitive to the parameters concerning Humus stock 2. This can be explained by the fact that this is a large stock, with very long residence times.
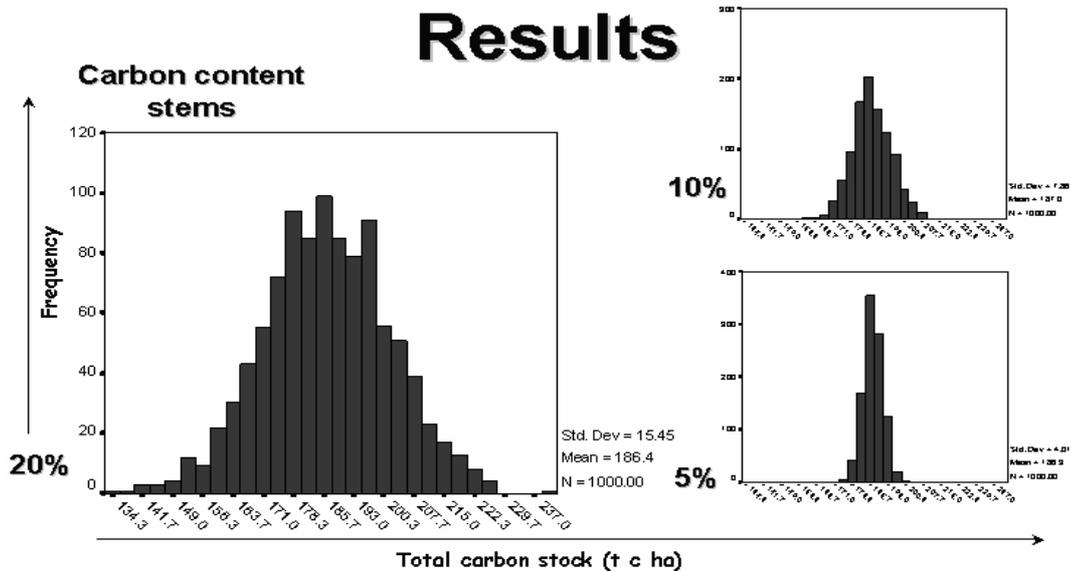
Figure 6.1: Results of the sensitivity analysis for carbon content in the stems. Input for stem carbon content was drawn from a normal distribution with a standard deviation of 20, 10 and 5% respectively.

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Annex 1   Overview of units and conversions

1 ton C= 1 Mg C
44/12 ton C = 1 ton CO_2

Annex 2   Acronyms

C	=	carbon
CAI	=	Current Annual Increment
CASFOR	=	Carbon Sequestration in Forested Landscapes
CATIE	=	Centro Agronómico Tropical de Investigación y Enseñanza
CDM	=	Clean Development Mechanism
CER	=	Certified Emission Reduction
CIECO	=	Laboratorio de Bioenergía, Centro de Investigaciones en Ecosistemas
DM	=	Dry matter
EFI	=	European Forest Institute
GWP	=	Global Warming Potential
IPCC	=	International Panel on Climate Change
JI	=	Joint Implementation
lCER	=	long term CER
LULUCF	=	Land use, land-use change and forestry
PET	=	Potential EvapoTranspiration
tCER	=	temporary CER
UNAM	=	National Autonomous University of México
UNFCCC	=	United Nations Framework Convention on Climate Change

Annex 3   FAQs

What is CO2FIX?
CO2FIX is a modelling frame where a user builds in his own (forest) data in order to simulate the long term carbon balance of a forest ecosystem. It provides annual output in terms of carbon stocks and fluxes.

Is there readily available input data for some tree species?
Yes, when you download a version of CO2FIX, you automatically receive a number of input forest types with it. In addition, you find a list of forest types on the Casfor web pages under 'case studies'.
Furthermore, you are welcome to send us your input forest types, and with your permission we will put them on the web.

What are the features of and options in each version of CO2FIX?
CO2FIX V 1.2 is the windows version of V1 which was originally developed by Frits Mohren. V1.2 has the possibility to simulate only one cohort (functional group of trees); i.e. an evenaged, monospecious stand of one ha. It has a simple soil module, simple management module, and a simple products module. It does give a full ecosystem carbon balance. If you are new in using models, we advise you to use this version first.

CO2FIX V 2.0 has a couple of main advances: main thing is the possibility to work with multiple cohort stands (still of one ha). These cohorts can influence each other through competition. V 2.0 has more advanced options to simulate mortality, management and its related mortality. Furthermore it has a more detailed products module and an improved soil module.

CO2FIX V 3.1 contains three new modules: a financial module, a bioenergy module and a carbon accounting module. Furthermore there are some minor changes in the soil and products module.

Can I simulate short rotation bioenergy plantations?
With some limitations yes. These and other special applications (like application to degrading grassland), are explained in the new manual for V 3.1.

Where can I find growth data for my simulations?
There is a list of yield table references at the
http://www.efi.fi/projects/forsce/yield_tables.html

Is there any CO2FIX related publications available?
You can download the publications of the CASFOR-II research team from the 'Results'
There are also references to other publications where CO2FIX is used at the 'Links'

Is it possible that you would check my simulations?
This is not possible. Even though another user of CO2FIX may be working on the same problem, we cannot give out names of registrants either.

Who are the contact persons in different institutions related to project?
-See 'Research team'

Where can I find references about biomass equations, biomass turnover rates, carbon content, and basic wood densities?
Some general refs:
DeAngelis, D. L., R. H. Gardner, et al. (1981). Productivity of forest ecosystems studied during the IBP: the woodlands data set. In: Reichle, D.E. (ed.) Dynamic properties of forest ecosystems. International Biological Programme 23. Cambridge University Press. Cambridge etc. pp. 567-672.

Cannell, M. G. R. e., Ed. (1982). World forest biomass and primary production data. Natural Environment Research Council. Institute of Terrestrial Ecology. Academic Press London New York. 391 p.

Attempts to bring together biomass equations, and biomass expansion factors (to simulate foliage, branches, roots) are undertaken in the COST E21 'Contribution of Forests and Forestry to Mitigate Greenhouse Effects'.
http://www.bib.fsagx.ac.be/coste21/

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http://www.fao.org/docrep/w4095e/w4095e00.htm#Contents
(includes an appendix with wood densities for many tropical species)

Global Forest Resources Assessment 2000

http://www.fao.org/docrep/004/y1997e/y1997e00.htm#Contents

Good Practice Guidance for Land Use, Land-Use Change and Forestry
http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_contents.htm

On the CARBODATA website, references can be found to relevant sources of information for carbon modelling. http://carbodat.ei.jrc.it/

Where can I find meteo data for the soil module?
http://www.worldclimate.com

Why should I register to use CO2FIX?
The purpose of the registration is to have insight to the user group of CO2FIX. The information you have provided will be used only for internal use and will not be given to any third party. With your e-mail address (which is obligatory in order to receive CO2FIX) it is possible for us to keep you informed on major changes and/or additions to CO2FIX. We will do that only in seldom cases through a mailing list address. Your personal email address is thereby secured.

What are the minimum requirements for CO2FIX to run on my computer?
The minimum requirements for installing the program on your personal computer are: Intel 80386 processor, 4 MB RAM memory, 4 MB free space on the hard disk and any Win32 operating system previously installed.

Annex 4   Troubleshooting

Problems:
1. Clicking the URL in the instant reply email that you got after registering gave the response that the page cannot be found.
   You may have waited longer than 24 hours with downloading since the registration you did. In this case just register again. The instant reply email that you will get, will give you the new URL from where to download the software.

2. Downloading took too long, and your connection failed. Just try again on a more quiet time of the day.

3. Clicking the URL in the instant reply email that you got after registering gave the response that the page cannot be found.
   The URL in the instant reply email that you got after registering may have truncated the URL address. Make the message box wide enough so that the whole URL is on one line.

Annex 5 Default parameters for products module

Table 1. Default, minimum and maximum parameter values for raw material allocation to different production lines for high processing and recycling efficiency system. The sum of each row must be one.

	Production line							
	Sawn wood		Boards		Paper		Firewood	
Raw material	Default	Min-max	Default	Min-max	Default	Min-max	Default	Min-max
Logwood	0.8	0.5-1.0	0.15	0.2-1.0	0.05	0-0.1	0	0-0
Pulpwood	0	0-0	0.05	0-0.4	0.9	0.8-1.0	0	0-0
Slash	0	0-0	0	0-0	0	0-0	1.0	1.0-1.0

Table 2. Default, minimum and maximum parameter values for raw material allocation to different production lines for low processing and recycling efficiency system. The sum of each row must be one.

	Production line							
	Sawn wood		Boards		Paper		Firewood	
Raw material	Default	Min-max	Default	Min-max	Default	Min-max	default	Min-max
Logwood	1	1-1	0	0-0	0	0-0	0	0-0
Pulpwood	0	0-0	0	0-0	0	0-0	0	0-0.2
Slash	0	0-0	0	0-0	0	0-0	0	0-0.1

Table 3. Default, minimum and maximum parameter values for the amount of primary product and process losses in different standard production system for high processing efficiency.

PRODUCTION LOSSES DURING MANUFACTURING

	To Sawn wood		To Boards		To Paper		To Firewood		To Mill site dump	
Production Line	Default	Min-max	default	Min-max	default	Min-max	default	Min-max	default	Min-max
Sawnwood	0.4	0.2-0.6	0.1	0-0.3	0.3	0.1-0.5	0.2	0-0.3	0	0-0.6
Boards	0	0-0	0.6	0.4-0.9	0.3	0-0.5	0.1	0.0-0.6	0	0-0.6
Paper	0	0-0	0.1	0-0.2	0.6	0.3-0.9	0.3	0-0.4	0	0-0.4
Firewood	0	0-0	0	0-0	0	0-0	0	0-0	1.0	1.0-1.0

Table 4. Default, minimum and maximum parameter values for the amount of primary product and process losses in different standard production system for low processing efficiency.

PRODUCTION LOSSES DURING MANUFACTURING

	To Sawn wood		To Boards		To Paper		To Firewood		To Mill site dump	
Production Line	default	Min-max	default	Min-max	default	Min-max	default	Min-max	default	Min-max
Sawnwood	0.3	0.2-0.5	0	0-0	0	0-0	0	0-0	0.7	0-0.9
Boards	0	0-0	0.3	0.1-0.8	0	0-0	0.1	0-0.7	0.6	0-0.7
Paper	0	0-0	0	0	0.25	0.2-0.5	0.25	0-0.8	0.5	0-0.8
Firewood	0	0-0	0	0-0	0	0-0	0.9	0.5-1.0	0	0-0

Table 5. Default, minimum and maximum parameter values for allocation of products to lifespan categories.

	Fraction allocated to					
	Long term		Medium term		Short term	
Product	Default	Min-max	Default	Min-max	Default	Min-max
Sawnwood	0.5	0.3-0.8	0.25	0.1-0.5	0.25	0.1-0.4
Boards	0.3	0.1-0.7	0.5	0.2-0.7	0.2	0.1-0.4
Paper	0.01	0-0.05	0.1	0-0.2	0.89	0.8-1.0

Table 6. Default, minimum and maximum parameter values for shares of recycling, burning and landfill at disposal.

	Fraction disposed to					
	Recycling		Energy		Landfill	
Life span	Default	Min-max	Default	Min-max	Default	Min-max
Long term	0.3	0.1-0.4	0.1	0-0.3	0.6	0.4-0.8
Medium term	0.1	0-0.4	0.1	0-0.4	0.8	0.6-1.0
Short term	0.4	0.2-0.6	0.5	0.25-0.8	0.1	0-0.3

Table 7. Default, minimum and maximum parameter values for recycling to life spans for each original life span category.

Original life span	Recycled to					
	Long term		Medium term		Short term	
	Default	Min-max	Default	Min-max	Default	Min-max
Long term	0.1	0-0.2	0.3	0-0.6	0.6	0.4-0.8
Medium term	0	0-0	0.1	0-0.4	0.9	0.6-1.0
Short term	0	0-0	0	0-0	1	1.0-1.0

Table 8. Default life spans.

Category	Half life (yr)
Long term products	30
Medium term products	15
Short term products	1
Mill site dump	5
Landfill	145

Annex 6   Default parameters bioenergy module

Table 1: Default parameter values for heating content of different fuels

Fuel	Heating value (MJ/kg)
Biomass (Slash Fuelwood)	15
Biomass (Industrial Residues Fuelwood)	15
Coal	28
Gas/oil	43.33
Kerosene	44.75
LPG	47.31
Natural gas	42.62
Oil	40.19

Table 2: Default parameter values for the Global Warming Potential of GHG, values taken for a 100 yr time-horizon. (Source: IPCC, 2001)

Greenhouse gas	Global warming potential
CO2	1
CH4	23
N2O	270
CO	2
TNMOC	12

Table 3: Default emission factors for technologies fuelled by biomass (g/kg of fuel)

Technology	Efficiency (%)	Emission factors CO_2	CH_4	N_2O	CO	TNMOC
Traditional Stove	13	0	9.4	0.08	64.7	9.65
Improved Cookstove	25	0	7.92	0.06	69.5	6.84
Charcoal Stove	29	0	7.8	0.08	250	10.5
Incineration high efficiency	24	0	0.4275	0.057	6.6	0
Stoker Boiler	24	0	0.225	0	8.85	0
Combustion plant<50MW (Boilers)	24	0	0.48	0.06	3.6	0.72
Combustion plant>=50 and <300MW (Boilers)	24	0	0.48	0.06	3.6	0.72
Stationary engine	24	0	0.48	0.06	3.6	0.72

Table 4: Default emission factors for technologies fuelled by coal (g/kg of fuel)

Technology	Efficiency(%)	Emission factors CO_2	CH_4	N_2O	CO	TNMOC
Cookstove	24	2550	7.98	0.0372	66.2	0.02
Stove	25	2540.75	7.98	0.0372	100.8	0
Furnace	25	2540.75	7.98	0.0372	13.44	0
Water Heater	25	2540.75	7.98	0.0372	0.504	0
Anthracite Space Heaters	25	2540.7518	6.45	0.0355	0	0
Power Plant	33	2425.15	0.0186	0.0426	0.2399	0

Table 5: Default emission factors for technologies fuelled by gas/oil (g/kg of fuel)

Technology	Efficiency(%)	Emission factors				
		CO_2	CH_4	N_2O	CO	TNMOC
Combustion plant (Boilers)	33	3206.42	0.065	0.08666	1.2999	0.065

Table 6: Default emission factors for technologies fuelled by kerosene (g/kg of fuel)

Technology	Efficiency(%)	Emission factors				
		CO_2	CH_4	N_2O	CO	TNMOC
Cookstove (a)	45	6958.63	1.25524	0.18706	0	0
Cookstove (b)	45	6175.5	1.47675	0.0358	85.025	35.5763

Table 7: Default emission factors for technologies fuelled by LPG (g/kg of fuel)

Technology	Efficiency(%)	Emission factors				
		CO_2	CH_4	N_2O	CO	TNMOC
Cookstove (a)	60	5057.439	0.99871	0.08894	0	0
Cookstove (b)	55	3075.15	0.04731	0.09462	1.1828	0.0946

Table 8: Default emission factors for technologies fuelled by natural gas (g/kg of fuel)

Technology	Efficiency(%)	Emission factors				
		CO_2	CH_4	N_2O	CO	TNMOC
Cookstove	55	3852.9332	0.8801	0.07842	0	0
Combustion plant <50MW (Boilers)	30	2439.995	0.6393	0.04262	1.1934	0.0852
Combustion plant >=50 and <300MW (Boilers)	30	2439.995	0.25572	0.04262	1.1934	0.0852

Table 9: Default emission factors for technologies fuelled by oil (g/kg of fuel)

Technology	Efficiency(%)	Emission factors				
		CO_2	CH_4	N_2O	CO	TNMOC
Combustion plant (Boilers)	33	3134.82	0.12057	0.08038	0.6029	0.1206

CO2FIX Decision tree

Tool to asses the type and eligibility of

Land Use Land Use Change and Forestry Activities

under the Kyoto protocol.

Legend:

= Question. This shape contains a question that can be answered with a Yes or a No. The answer then leads to another question or to a result.

= Positive result. This shape contains a positive result based on the answers to the previous questions. The shape will also contain an explanation of the modalities and regulations of the Kyoto protocol that apply to the activity that is assessed.

= Negative result. This shape contains a negative result based on the answers to the previous questions. The shape will also contain an explanation of the reason why the assessed activity is not eligible under the Kyoto protocol.

National I

Is the activity that you employ related to forest management or to land use change to or from forest?

— N → Please proceed with the "National II" decision tree

— Y ↓

Was the land use in the area where the activity takes place forest before the activity was implemented?

— N → Was the land use in the area for 50 years or more different to that of forest?

— N → Was the area without forest (clear cut) the 31st of December 1989?

— N → The activity does not meet the requirements of the Kyoto protocol to fall under Afforestation or Reforestation options and is therefore not eligible to credit sequestered Carbon.

The activity falls under the Afforestation, Reforestation and Deforestation (Art. 3.3) options of the Kyoto protocol. Under this option Reforestation and Afforestation activities can be credited completely by Annex I countries. The Carbon that is sequestered through this activity will be part of the nations national Carbon emission inventory.

Did the activity change the management of the forest?

— N → Did the activity involve the permanent removal of trees beyond the definition criteria of forest and did it change the land use in the area from forest to one other than forest?

— N → The activity does not meet the requirements of the Kyoto protocol to fall under deforestation.

The activity falls under the Deforestation (Art. 3.3) options of the Kyoto protocol. Under this option Deforestation activities have to be included in the national Carbon inventories.

Did your country elect Forest Management as a Kyoto protocol option for the area where the activity takes place?

— N → Is the area used for other purposes that forest alone, like crop production or grazing land?

— N → The activity does not meet the requirements of the Kyoto protocol. This type of project is only eligible under the Kyoto protocol when the hosting country has elected this type as eligible. No credits or debits can be gained by this project.

— Y → Please proceed with the "National II" decision tree

The activity falls under the Land Use, Land Use Change and Forestry options (Art. 3.4) of the Kyoto protocol. For the first commitment period (2008-2012), the amount of credits that can be obtained by Annex I countries from forest management activities together with forest management activities under Joint Implementation projects is bound to a maximum value (CAP) that is specified per Annex I country (Annex Z). This CAP does not apply if the sequestered Carbon compensates for possible Carbon emissions in Afforestation, Reforestation or Deforestation (Art. 3.3) activities, up to a maximum of 9.0 Mt times 5.

National II

Is the activity related to a land use change between cropland, grassland, wetland and\or settlements or any other category?

— Y → The activity does not meet the requirements of the Kyoto protocol to fall under the Land Use Change options and is therefore not eligible to credit sequestered Carbon.

— N ↓

Is the activity related to a change in management of dry land, grassland or wetland?

— N → The activity does not meet the requirements of the Kyoto protocol to fall under the Land Use Change options and is therefore not eligible to credit sequestered Carbon.

— Y ↓

Is the activity part of a system on which agricultural crops are grown and on land that is set aside or temporarily not being used for crop production?

— Y → Did your country elect cropland management as a Kyoto protocol option for the area where the activity takes place??

— Y → The activity falls under the Land Use Land Use Change and Forestry options (Art. 3.4) of the Kyoto protocol. For the first commitment period, accountable anthropogenic greenhouse gas emissions by sources and removals by sinks resulting from cropland management, grazing land management or revegetation under Article 3.4, shall be equal to anthropogenic greenhouse gas emissions by sources and removals by sinks in the commitment period, less five times the anthropogenic greenhouse gas emissions by sources and removals by sinks resulting from these eligible activities in the base year of that Party, while avoiding double accounting.

— N → This activity is not eligible for Carbon crediting. Carbon sequestration by cropland management is optionally and has to be elected by countries in order to be creditable.

— N ↓

Is the activity part of a system of practices on land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced?

— Y → Did your country elect grazing land management as a Kyoto protocol option for the area where the activity takes place?

— N → This activity is not eligible for Carbon crediting. Carbon sequestration by grazing land management is optionally and has to be elected by countries in order to be creditable.

— N ↓

Is the activity a direct human induced activity to increase Carbon stocks on sites through the establishment of vegetation that covers a minimum area of 0.05 and that does not meet the definition of Afforestation, Reforestation, Forest Management, Cropland Management or Grassland Management?

— Y → Did your country elect revegetation as a Kyoto protocol option for the area where the activity takes place?

— N → This activity is not eligible for Carbon crediting. Carbon sequestration by revegetation is optionally and has to be elected by countries in order to be creditable.

— N → This activity is not eligible for Carbon crediting.

Joint Implementation I

Is the activity that you employ related to forest management or to land use change to or from forest? — N → Please proceed with the "Joint Implementation II" decision tree

↓ Y

Was the land use in the area where the activity takes place forest before the activity was implemented? — → Was the land use in the area for 50 years or more different to that of forest? — N → Was the area without forest (clear cut) the 31st of December 1989? — N → The activity does not meet the requirements of the Kyoto protocol to fall under Afforestation or Reforestation options and is therefore not eligible to credit sequestered Carbon.

(Y / Y) → The activity is an Afforestation or Reforestation (Art. 3.3) option of the Kyoto protocol under the Joint Implementation (art. 6) provision. Sequestered Carbon can be credited by Annex I countries. Emission reduction units for these activities can only be transferred to an other Annex I country when the quantified emission limitation or reduction commitment is already realised by the hosting country.

Did the activity change the management of the forest? — N → Did the activity involve the permanent removal of trees beyond the definition criteria of forest and did it change the land use in the area from forest to one other than forest? — N → The activity does not meet the requirements of the Kyoto protocol.

↓ Y

The activity falls under the Deforestation (Art. 3.3) option of the Kyoto protocol. Under this option Deforestation activities have to be included in the national Carbon inventories. Carbon credit transfer to an other Annex I country by the Joint Implementation mechanism seems irrelevant here.

Did your country elect Forest Management as a Kyoto protocol option for the area where the activity takes place? — N → Is the area used for other purposes that forest alone, like crop production or grazing land? — N → The activity does not meet the requirements of the Kyoto protocol. This type of project is only eligible under the Kyoto protocol when the hosting country has elected this type as eligible. No credits or debits can be gained by this project.

↓ Y

The activity is forest management (Art. 3.4) under under the Joint Implementation (Art. 6) provision. For the first commitment period (2008-2012), the amount of credits that can be obtained by Annex I countries from forest management activities under Joint Implementation projects together with forest management activities inside the country is bound to a maximum value (CAP) that is specified per Annex I country (Annex Z). Carbon sequestration for these activities can only be transferred to an other Annex I Country when the quantified emission limitation or reduction commitment is already realised by the hosting country.

(Y) → Please proceed with the "Joint Implementation II" decision tree

Joint Implementation II

Is the activity related to a land use change between cropland, grassland, wetland and\or settlements or any other category? — Y → The activity does not meet the requirements of the Kyoto protocol to fall under the Land Use Change options and is therefore not eligible to credit sequestered Carbon.

↓ N

Is the activity related to a change in management of dry land, grassland or wetland? — Y → The activity does not meet the requirements of the Kyoto protocol to fall under the Land Use Change options and is therefore not eligible to credit sequestered Carbon.

↓ N

Is the activity part of a system on which agricultural crops are grown and on land that is set aside or temporarily not being used for crop production? — Y → Did your country elect cropland management as a Kyoto protocol option for the area where the activity takes place?? — Y →

↓ N (from cropland management): This activity is not eligible for Carbon crediting. Carbon sequestration by cropland management is optionally and has to be elected by countries in order to be creditable.

↓ N

Is the activity part of a system of practices on land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced? — Y → Did your country elect grazing land management as a Kyoto protocol option for the area where the activity takes place? — N → This activity is not eligible for Carbon crediting. Carbon sequestration by grazing land management is optionally and has to be elected by countries in order to be creditable.

↓ N

Is the activity a direct human induced activity to increase Carbon stocks on sites through the establishment of vegetation that covers a minimum area of 0.05 and that does not meet the definition of Afforestation, Reforestation, Forest Management, Cropland Management or Grassland Management? — Y → Did your country elect revegetation as a Kyoto protocol option for the area where the activity takes place? — N → This activity is not eligible for Carbon crediting. Carbon sequestration by revegetation is optionally and has to be elected by countries in order to be creditable.

↓ N

This activity is not eligible for Carbon crediting.

The activity falls under the Land Use Land Use Change and Forestry options (Art. 3.4) of the Kyoto protocol. For the first commitment period, accountable anthropogenic greenhouse gas emissions by sources and removals by sinks resulting from cropland management, grazing land management or revegetation under Article 3.4, shall be equal to anthropogenic greenhouse gas emissions by sources and removals by sinks in the commitment period, less five times the anthropogenic greenhouse gas emissions by sources and removals by sinks resulting from these eligible activities in the base year of that Party, while avoiding double accounting.

Clean Development Mechanism (CDM)

Was the land use in the area where the activity takes place forest before the activity was implemented?

→ Y →

The activity is not eligible under the Kyoto protocol. Under Art 12 (CDM), activities aiming at the prevention of deforestation or activities that aim at improving Carbon sequestration in forests through improved or changing management are not eligible. Therefore the carbon stored in the forest can not be credited.

N ↓

Was the land use in the area for 50 years or more different to that of forest?

Y →

Did you establish a forest that will meet the forest definition criteria?

Y →

Was the activity officially submitted for registration before the 31st of December 2005?

Y →

The activity falls under the Clean Development Mechanism (Art. 12) of the Kyoto protocol. Under this mechanism reforestation and afforestation activities can be credited by Annex I countries up to 1% of their assigned amount. Because the activity was submitted for registration before the 31st of December 2005, Carbon that is sequestered prior to the date of its registration, but not before the 1st of January 2000 can be credited.

N ↓ (from "Was the activity officially submitted...")

The activity falls under the Clean Development Mechanism (Art. 12) of the Kyoto protocol. Under this mechanism reforestation and afforestation activities can be credited by Annex I countries up to 1% of their assigned amount. Because the activity was not submitted for registration before the 31st of December 2005, only Carbon that is sequestered after the registration date can be credited.

N ↓ (from "Was the land use in the area for 50 years...")

Was the area without forest (clear cut) the 31st of December 1989?

Y →

N ↓ (from "Did you establish a forest...")

N ↓ (from "Was the area without forest...")

The activity does not meet the requirements of the Kyoto protocol to fall under Afforestation or Reforestation options and is therefore not eligible to credit sequestered Carbon for a Clean Development Mechanism (CDM) like project..