

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

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Wageningen, 2004



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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, M. Kanninen, J. Liski, O. Masera, G.M.J. Mohren, G.J. Nabuurs, L. Pedroni, A. Pussinen, A. Vallejo, T. Palosuo, 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.

CASFOR Team,
Wageningen, Patzcuaro, Turrialba, Joensuu, October 2004

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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 how to parameterise some special situations. Further a group 'CO2FIX' will be added to your Programs menu, including among others links to the executable and the help, and an uninstaller.

General description

CO2FIX V 3.1 is a simple carbon bookkeeping model that consists of six modules:

- biomass module
- soil module
- products module
- bioenergy module
- financial module
- carbon accounting module

Figure 1 illustrates the modular structure of the model. The biomass module converts volumetric net annual increment data with the help of additional parameters to annual carbon stocks in the biomass compartment. Turnover and harvest parameters drive the fluxes into the soil and the products compartment. In the soil module, decomposition of litter and harvest residues is simulated using basic climate and litter quality information. The fate of the harvested carbon is determined in the wood products module, using parameters like processing efficiency, product longevity and recycling. In the bioenergy module, discarded products or by-products from the product module can be used to generate bioenergy, using varying technologies. 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 profitability of the different scenarios.

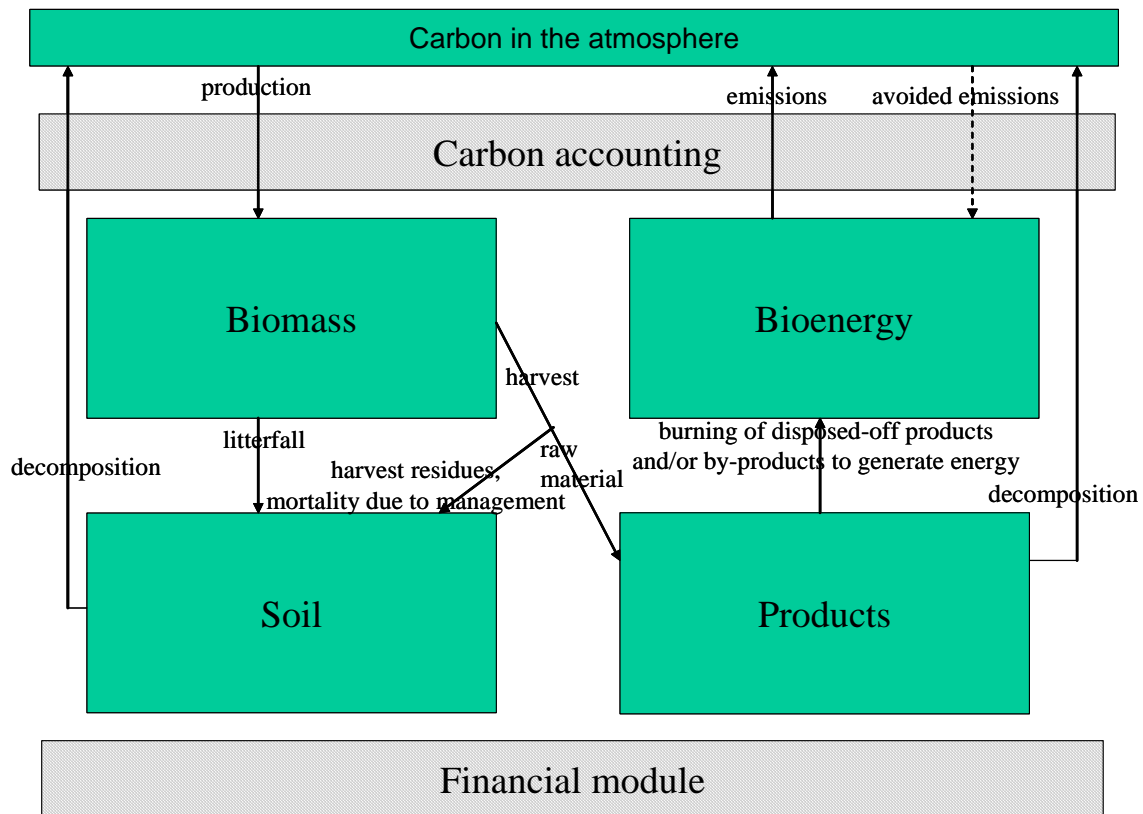


Figure 1. The modules of CO2FIX V 3.1.

This easy-to-use 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.

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 2).



Figure 2. 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;
- An icon for the general parameter settings of the project
- Six icons for the parameterisation menus of the six modules (biomass, soil, products, carbon accounting, 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 CO2FIX icon.

Within this manual, we will mostly follow the Pine-Oak case study (Central Mexico_pine_oak.co2) 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.

Biomass module

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).

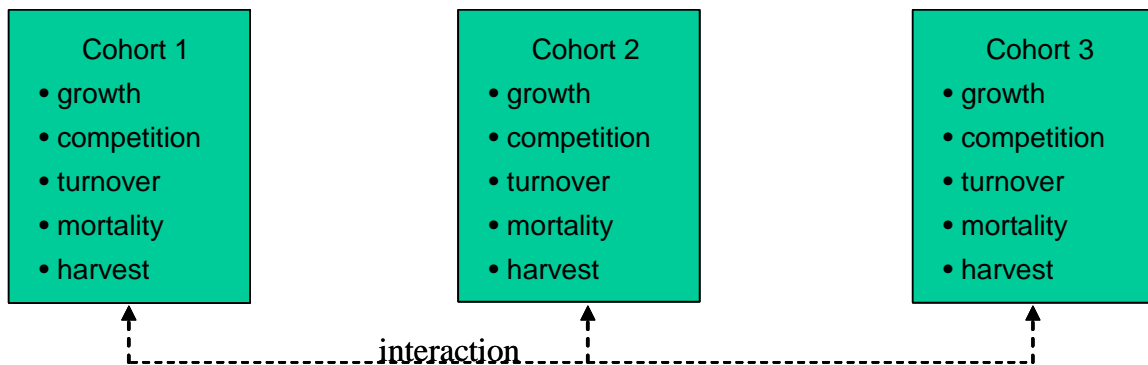


Figure 3. Processes within and interaction between cohorts.

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 4). This latter information is used to characterise the quality of the litter input to the soil module.

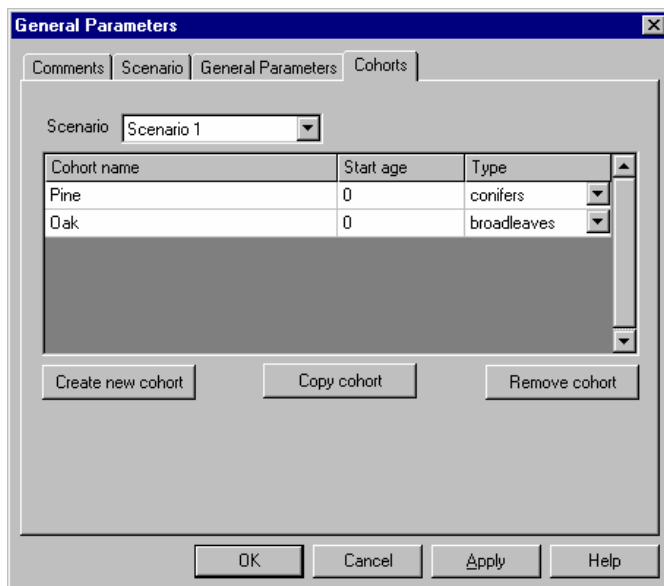


Figure 4. **Cohorts** screen in main menu **General Parameters**.

Stemwood growth

The driving factor of each cohort in the biomass module is the stemwood production in volume per ha (Figure 5), 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.

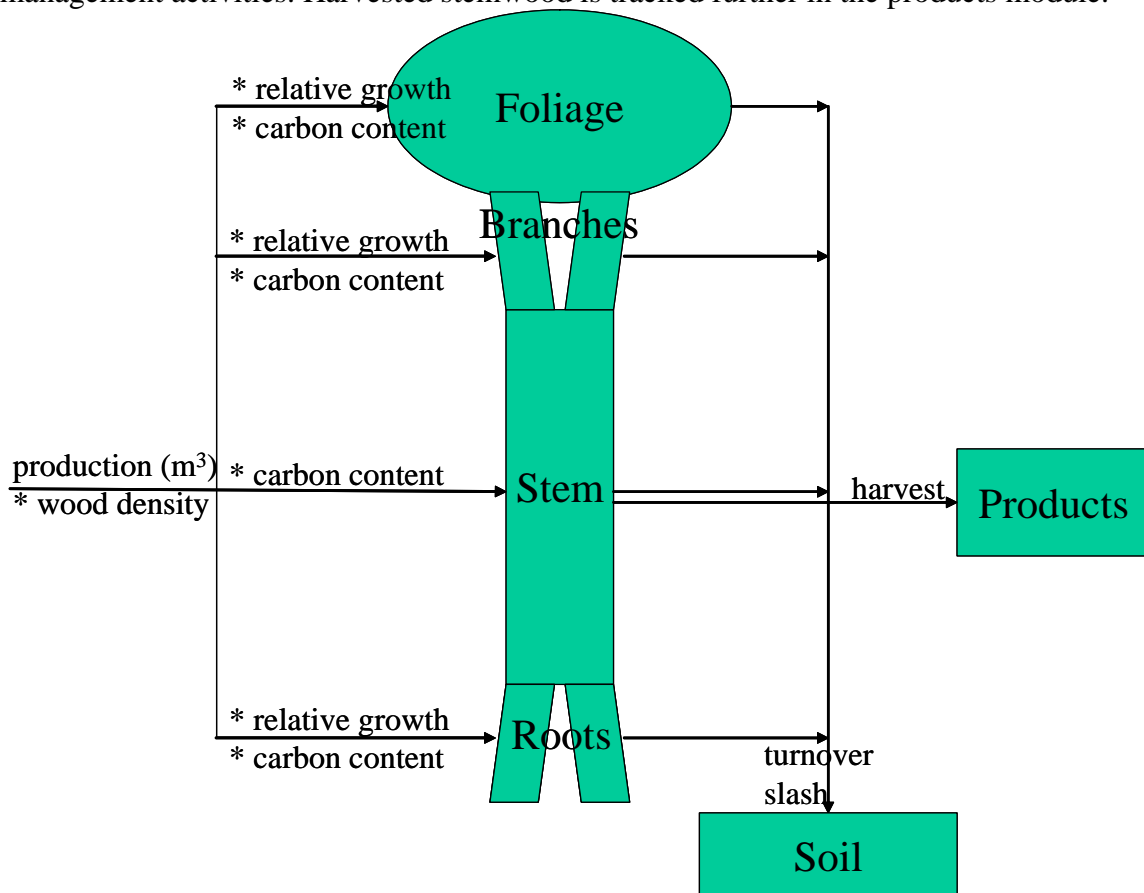


Figure 5. Schematic representation of processes and flows in the biomass module for one cohort.

CO2FIX V 3.1 allows two basic approaches for modelling growth of the cohorts:

1. tree growth as a function of tree or stand age, and
2. 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 6a). 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 6b).

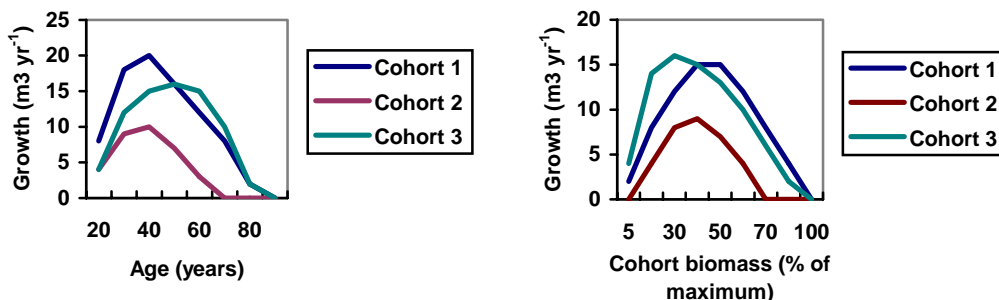


Figure 6a. Current annual volume increment (CAI) of three cohorts in a forest stand as a function of cohort age. (*Exemplary only; growth will normally not decline to 0*)

Figure 6b. Current annual increment (CAI) ($\text{m}^3 \text{ha}^{-1} \text{yr}^{-1}$) 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 7). 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 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.

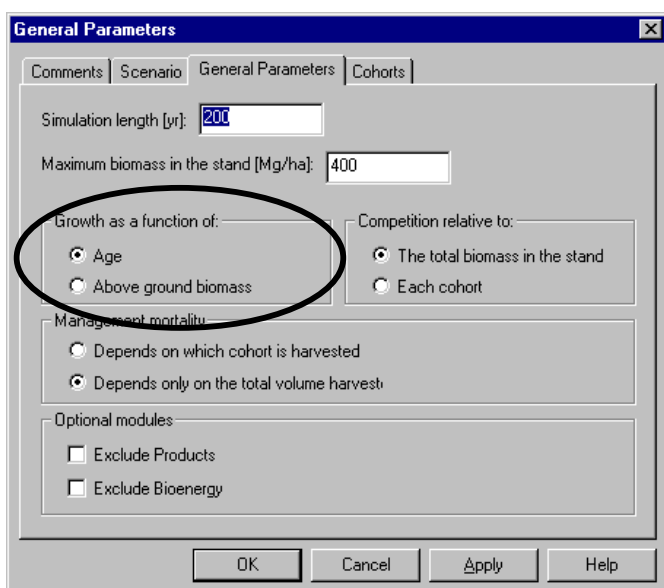


Figure 7. **General Parameters** screen, in main menu **General Parameters**, with in this case growth as a function of age.

Table 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 8 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.

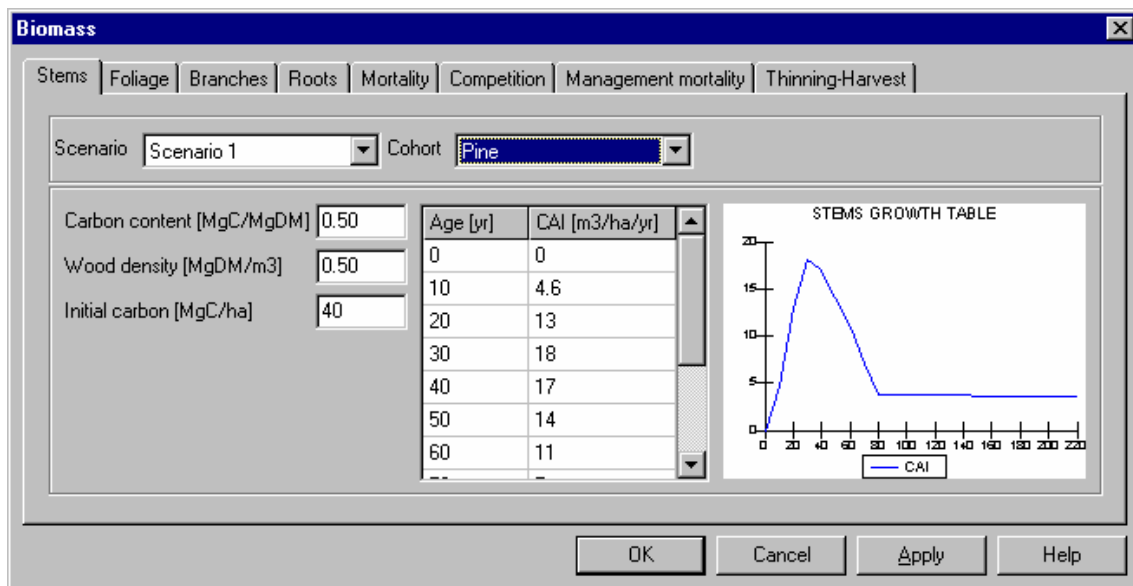


Figure 8. *Stems* parameterisation screen in main menu **Biomass**.

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 9).

$$B_i = F_i * B_s$$

Where:

F_i = relative biomass allocation coefficient (F_f for foliage, F_b for branches, F_r for roots)

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

B_s = growth of stem biomass

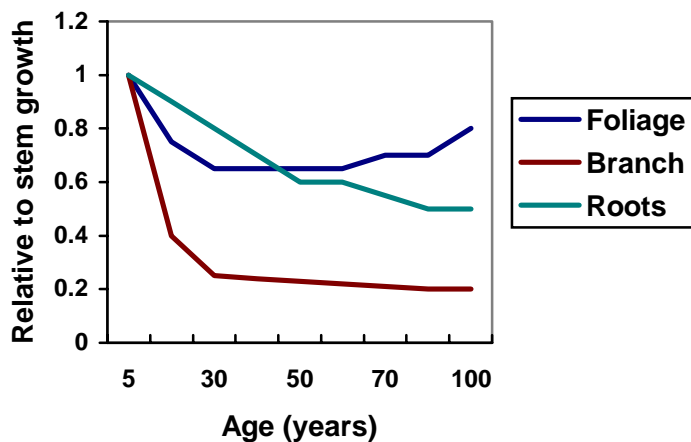


Figure 9. Example of the growth of biomass of foliage, branches and roots relative to stem biomass growth (biomass allocation coefficient) as a function of age.

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 10 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 10 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.

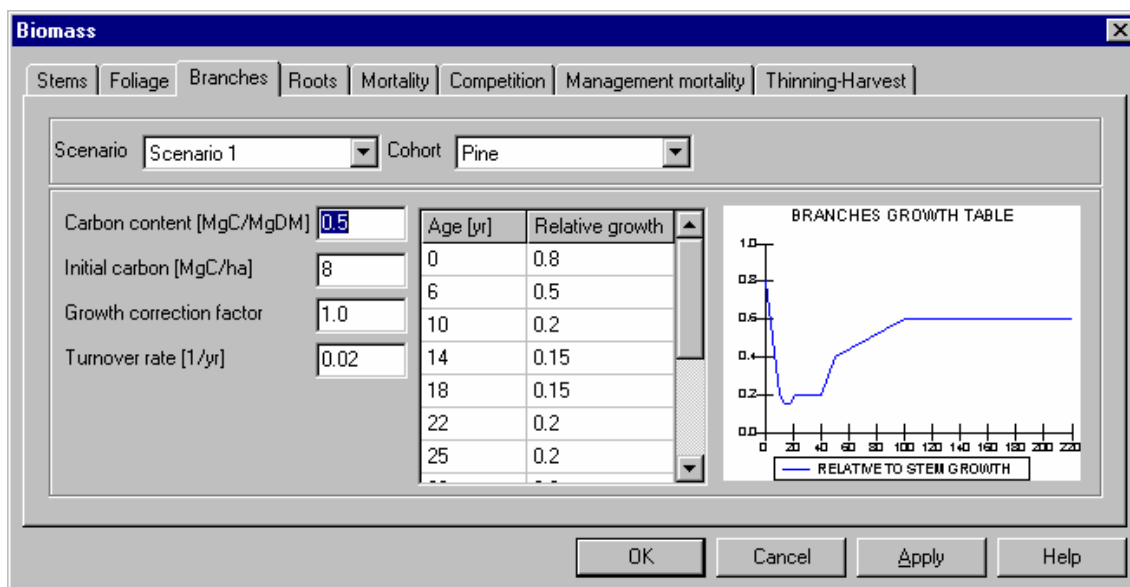


Figure 10. Branches parameterisation screen in main menu ‘biomass’

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.

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 7). 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 11). When the initial planting density is low, initial mortality may be low as well (e.g. like cohort 2 and 3 in Figure 11). 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 11). If growth is dependent on the ratio of actual biomass over maximum biomass, natural mortality should be parameterised according to this ratio as well.

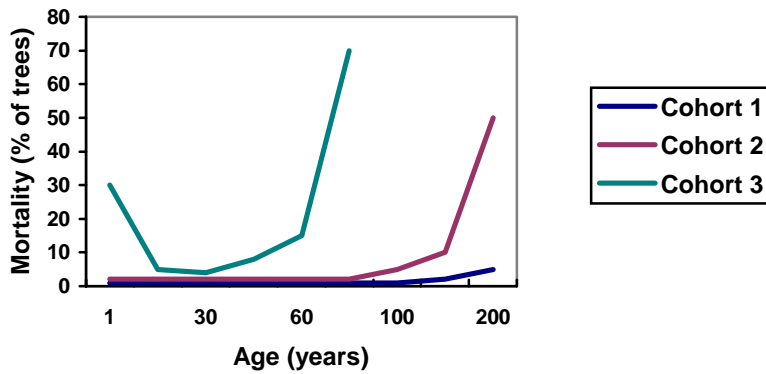


Figure 11. Mortality due to senescence of three cohorts parameterised as a function of stand age. Note that these are hypothetical curves displaying very high mortality rates.

The parameterisation of natural mortality is done in the **Biomass** main menu, tab **Mortality**. Figure 12 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 if the forest is regularly managed or not.

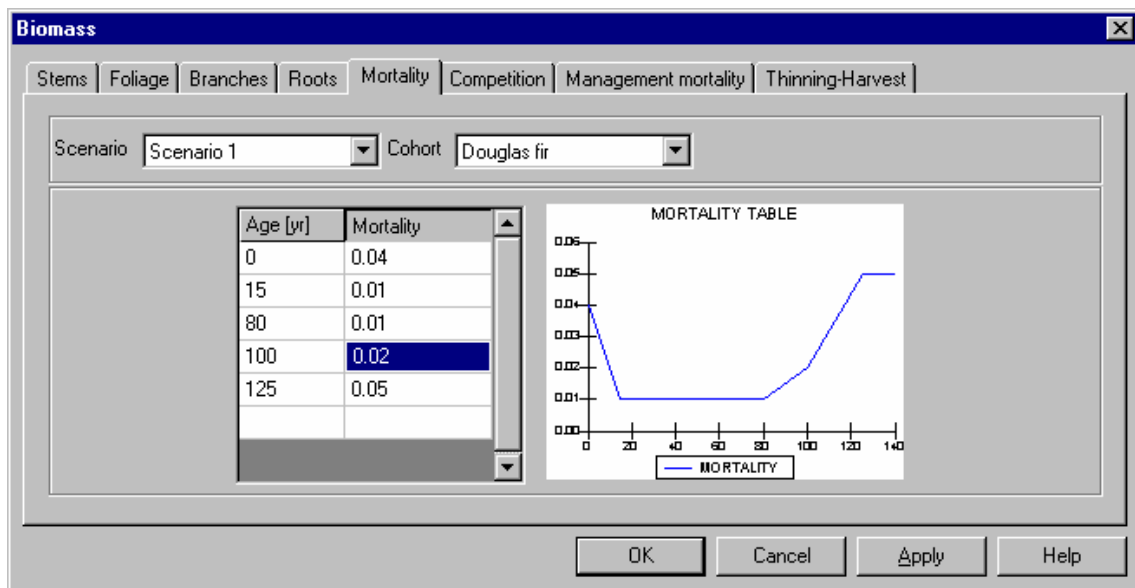


Figure 12. **Mortality** parameterisation screen in main menu **Biomass**.

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 13, 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 m³; case two: 20 m³). 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%.

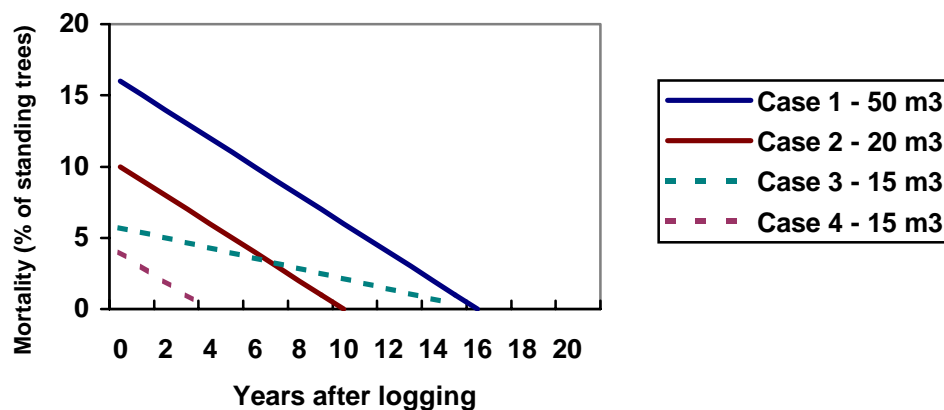


Figure 13. Mortality caused by damage from logging in four hypothetical cases, depending on the intensity of logging.

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 14). The other parameters can be found in the **Biomass** main menu, tab *Management mortality* (Figure 15).

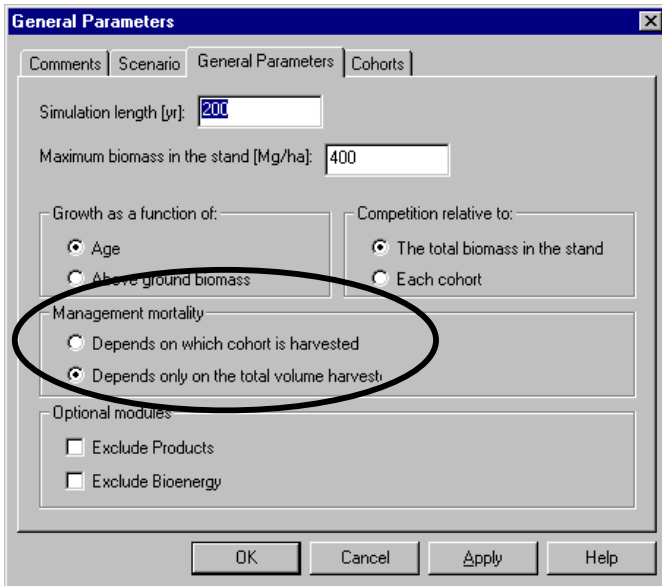


Figure 14. *General Parameters* screen, in main menu **General Parameters**, with in this case management mortality as a function of the total volume harvested.

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.

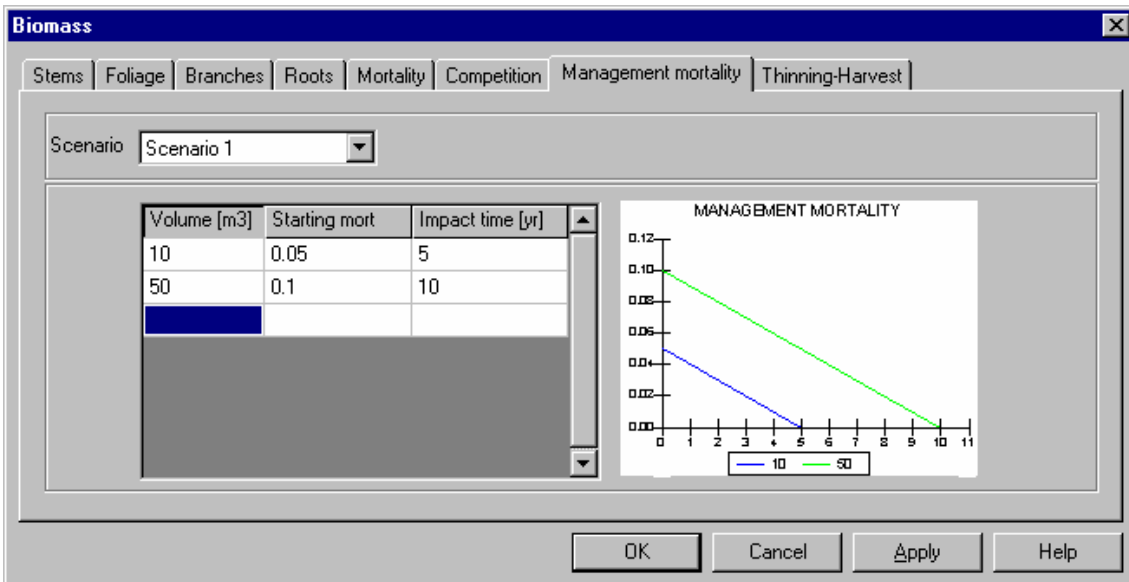


Figure 15. Parameterisation of management mortality, where management mortality is only dependent on the total volume harvested.

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 16 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).

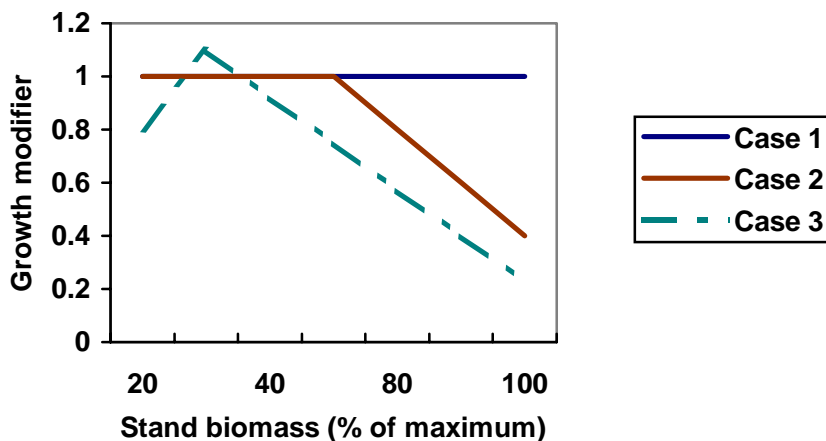


Figure 16. Growth modifier as a function of total stand biomass (Mg ha^{-1}) in three cases.

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 17). The other parameters can be found in the **Biomass** main menu, tab *Competition* (Figure 18 and 19).

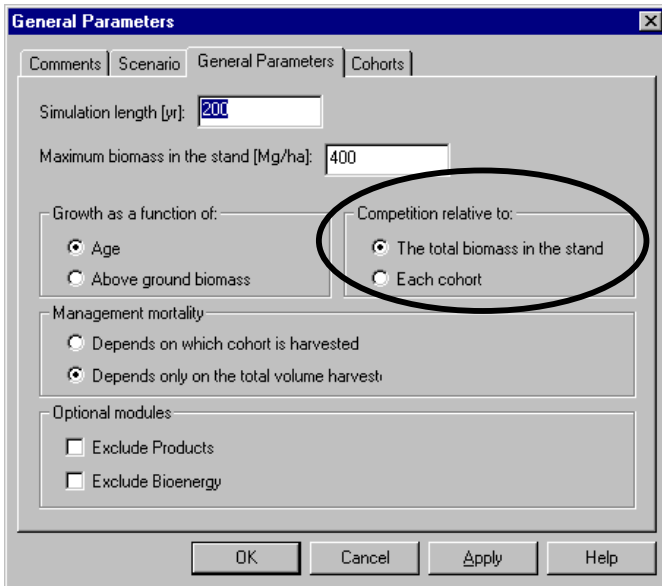


Figure 17. *General Parameters* screen, in main menu **General Parameters**, with in this case competition as a function of the total biomass in the stand.

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 18.

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 19. 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 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.

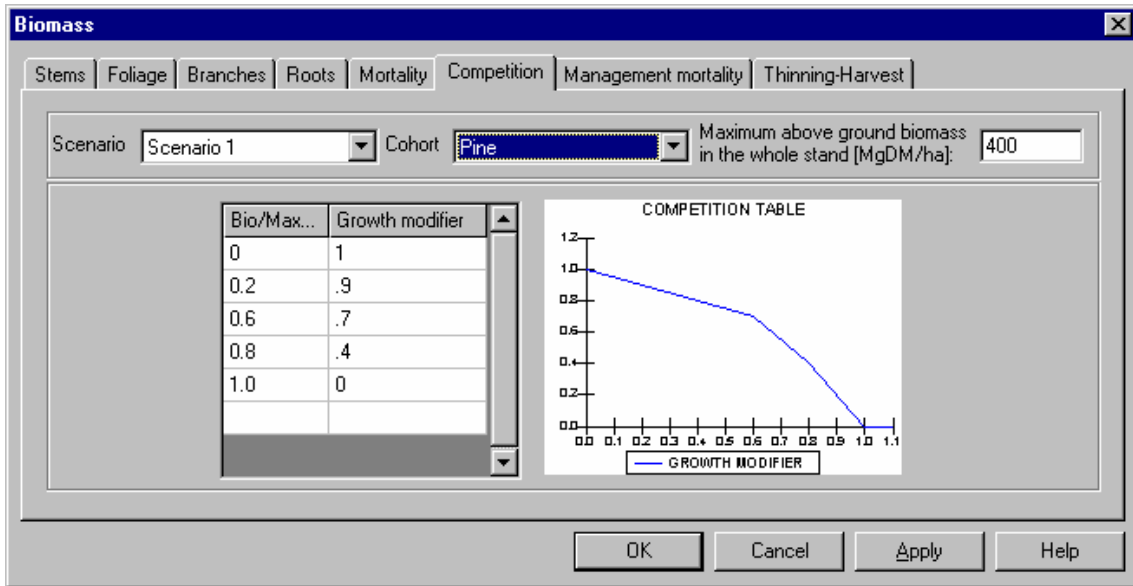


Figure 18. *Competition* relative to total biomass in the stand

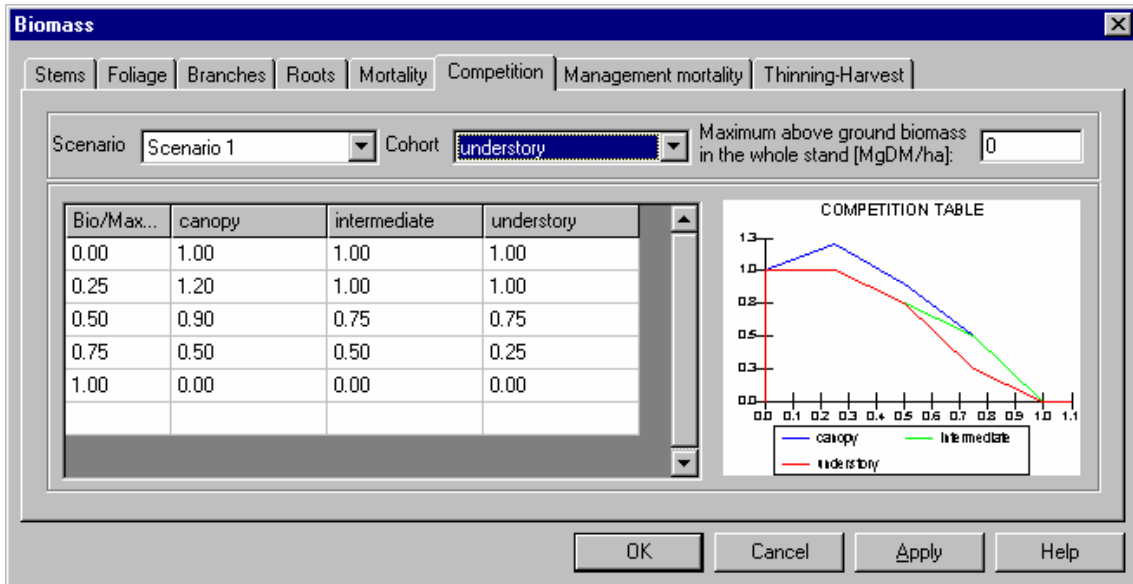
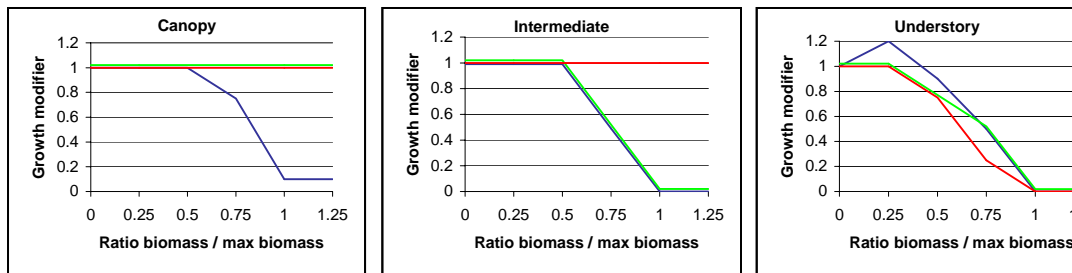


Figure 19. *Competition* relative to each cohort

Box 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.

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. Thinning and final felling can be defined for each cohort separately. A thinning is described by the following parameters:

- Age at which the intervention takes place;
- Intensity of the intervention (fraction of cohort biomass removed);
- 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 20). 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.

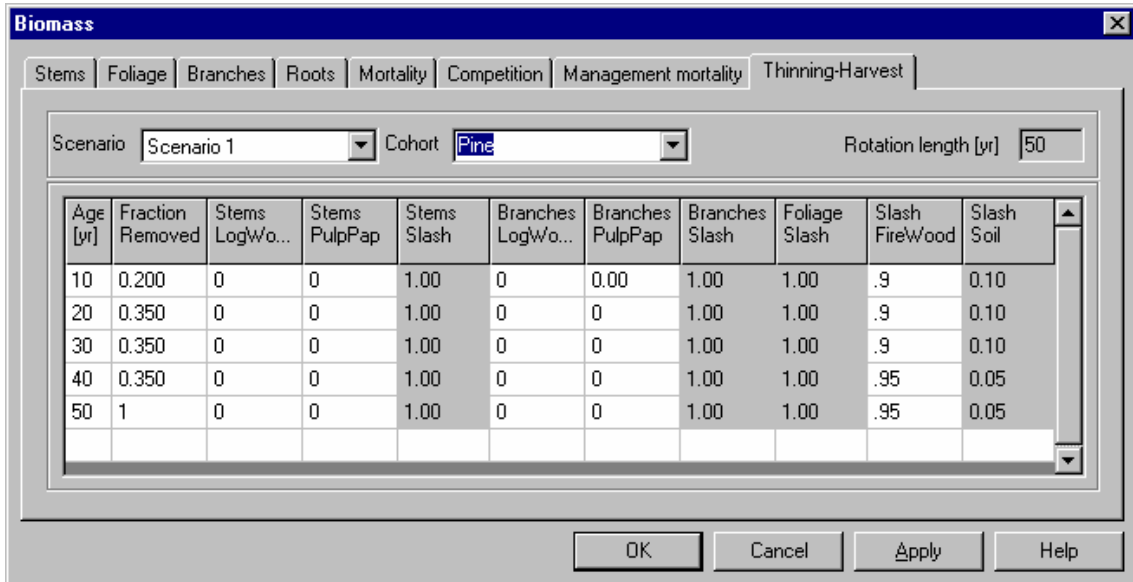


Figure 20. Thinning and final harvesting table

Soil module

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. 2003, Palosuo et al. in prep.).

Structure

The soil module consists of three litter compartments and five decomposition compartments (Figure 21). 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.

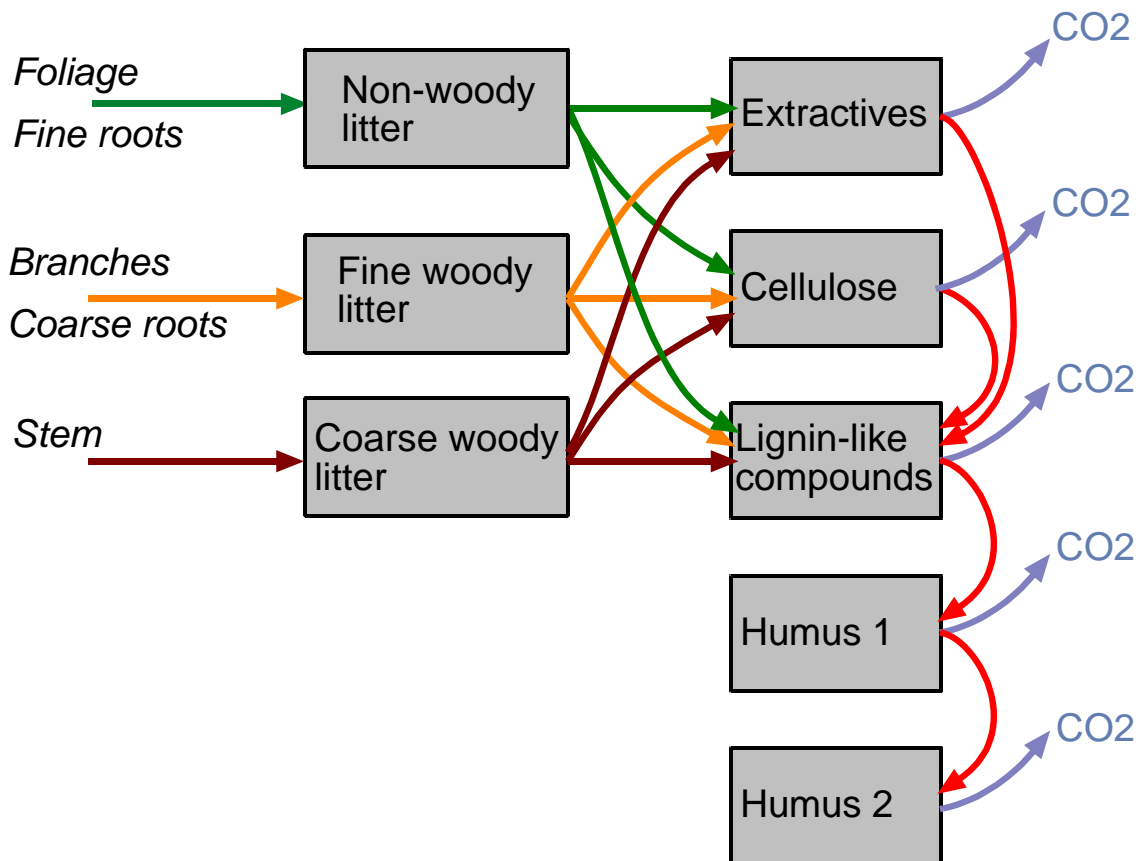


Figure 21. Flow chart of the soil model. The boxes represent carbon compartments, and the arrows represent carbon fluxes.

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 22). These are effective temperature sum (*degree days* above zero) over the year ($^{\circ}\text{C d}$), *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 23), 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.

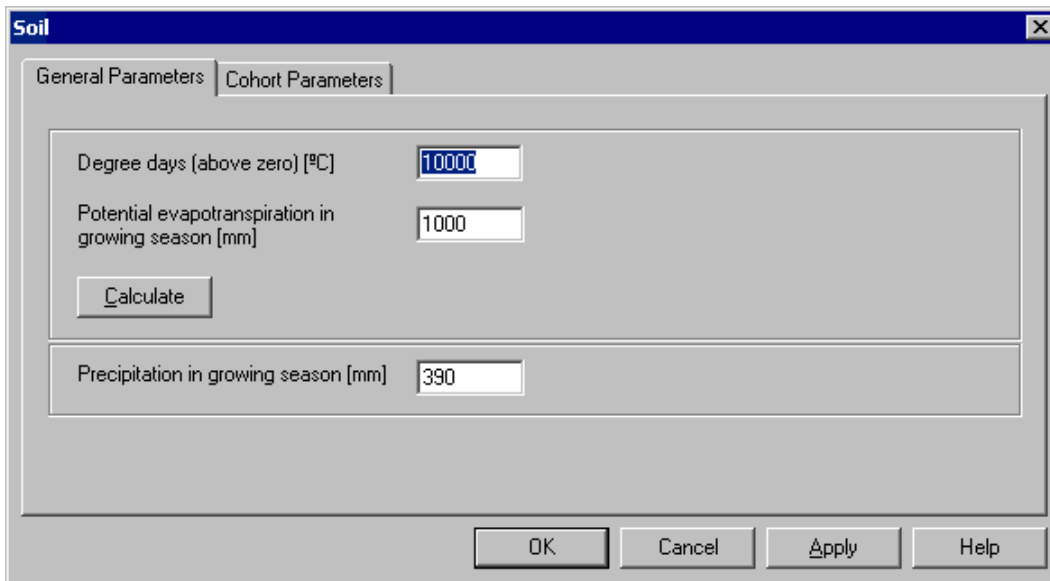


Figure 22. Main window for the **Soil** module.

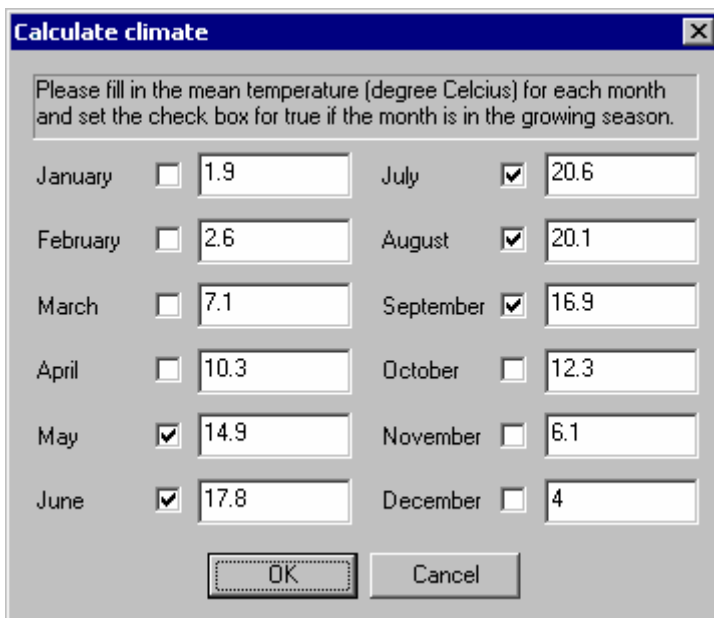


Figure 23. Calculate climate window, with in this case a growing season from May till September.

For each *cohort* in each *scenario*, the carbon stocks in each soil compartment (i.e. the boxes in Figure 21) must be initialised. This can be done through manually inserting available data in the **Cohort** parameters tab (Figure 24), 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 25) 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.

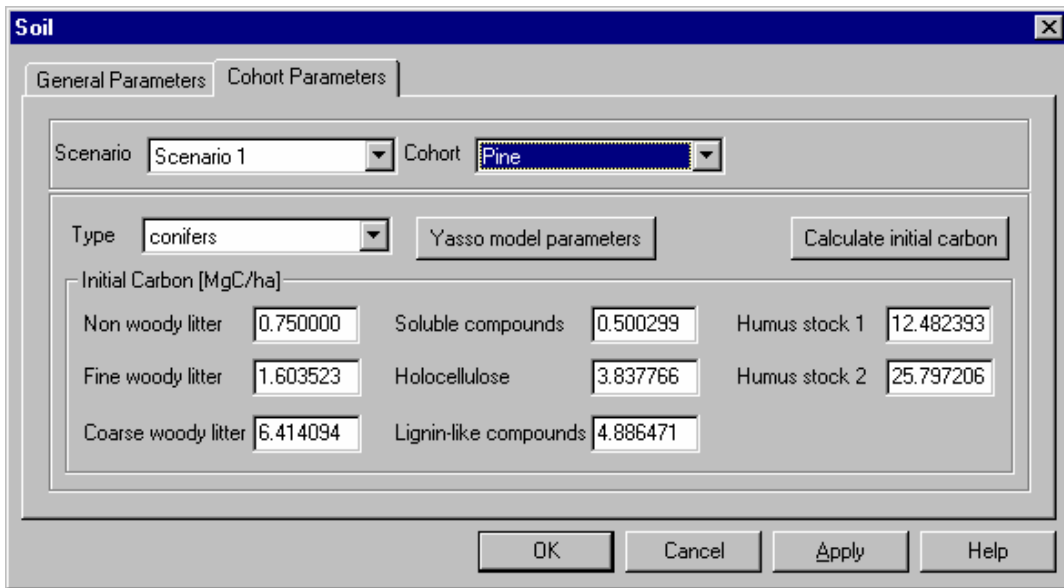


Figure 24. Soil initial stocks per compartment in the soil module.

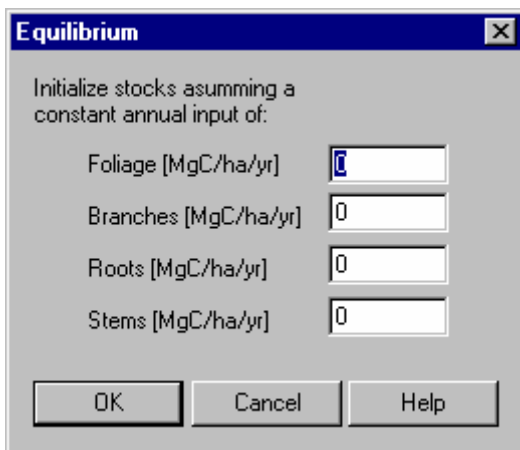


Figure 25. Window to initialise soil carbon stocks through litterfall rates of the previous land use.

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 26). 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.

Yasso model parameters [X]

Temperature sensivity for humus decomposition c Initial decomposition rate for soluble compounds $K0sol$

Litter composition

PROPORTION OF: C O N S I S T I N G O F :

	Soluble compounds	Holocellulose	Lignin-like compounds
Non woody litter	$Cnwsol$ <input type="text" value="0.27"/>	$Cnwlcel$ <input type="text" value="0.51"/>	$Cnwllig$ <input type="text" value="0.220000"/>
Fine woody litter	$Cfwlsol$ <input type="text" value="0.03"/>	$Cfwlcel$ <input type="text" value="0.65"/>	$Cfwllig$ <input type="text" value="0.320000"/>
Coarse woody litter	$Ccwsol$ <input type="text" value="0.03"/>	$Ccwlcel$ <input type="text" value="0.69"/>	$Ccwllig$ <input type="text" value="0.280000"/>

OK Cancel Help

Figure 26. Soil module internal parameters.

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 27). 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.

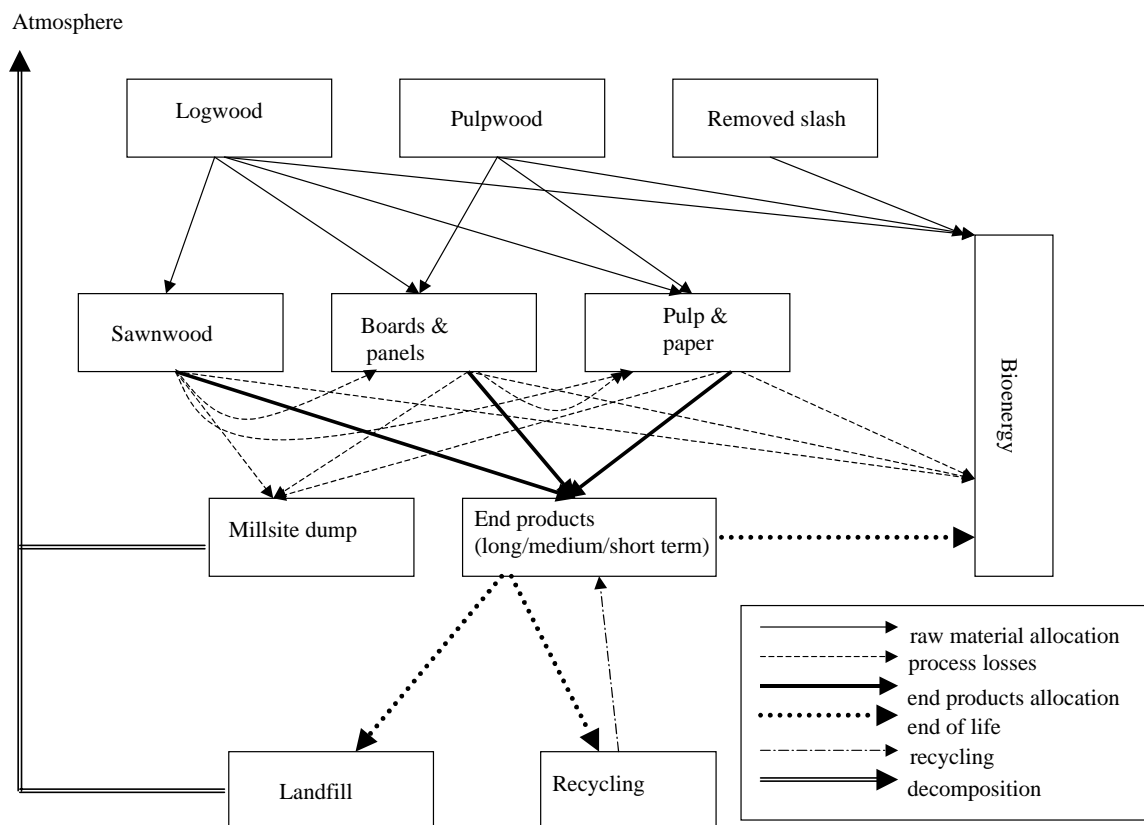


Figure 27. Outline of the wood products module. Boxes are stocks of carbon; the arrows show transfers of carbon between different phases of the chain (from harvest to final allocation). The distinction between logwood, pulpwood and slash is done in the biomass module.

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 28). This option should be used when simulating 'real world' carbon crediting projects, since products are to be excluded according to the Marrakech accords.

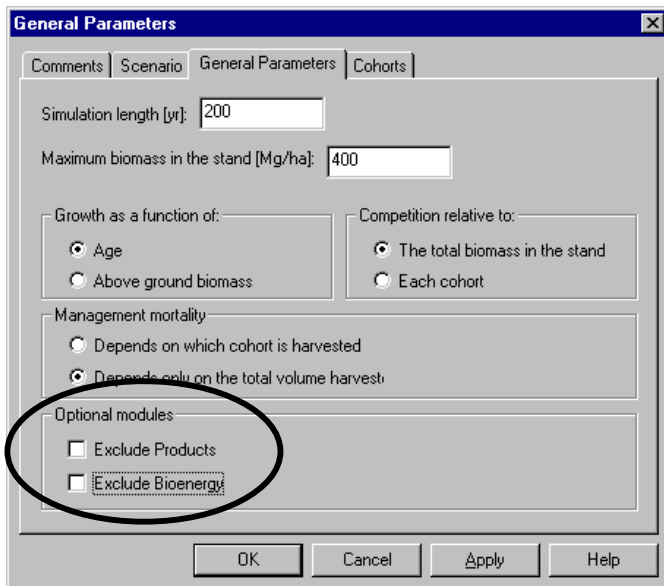


Figure 28. *General Parameters* screen, in main menu **General Parameters**, with the options to exclude the products module and/or the bioenergy module.

Production line

The first tab, *Production line*, contains the parameters for the processes of raw material allocation and process losses (Figure 29). 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 29. Parameterising the products module: raw material allocation and processing losses

End products

The second tab, *End products*, contains parameters for the end products allocation process and the end of life process (Figure 30). 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 $\text{short term} = 1 - (\text{long term} + \text{medium term})$

The bottom part of the window in Figure 30 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.

PRODUC-TION LINE	FRACTION ALLOCATED TO		
	Long term	Medium term	Short term
Sawnwood	0.50	0.25	0.250000
Boards	0.30	0.50	0.200000
Paper	0.01	0.10	0.890000

PRODUCT TYPE	FRACTION DISPOSED TO		
	Recycling	Energy	Landfill
Long term	0.1	0.8	0.100000
Medium term	0.1	0.8	0.100000
Short term	0.2	0.75	0.050000

Figure 30. Parameterising the products module: life span allocation and end-of-life disposal

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 31). 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 32). 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.

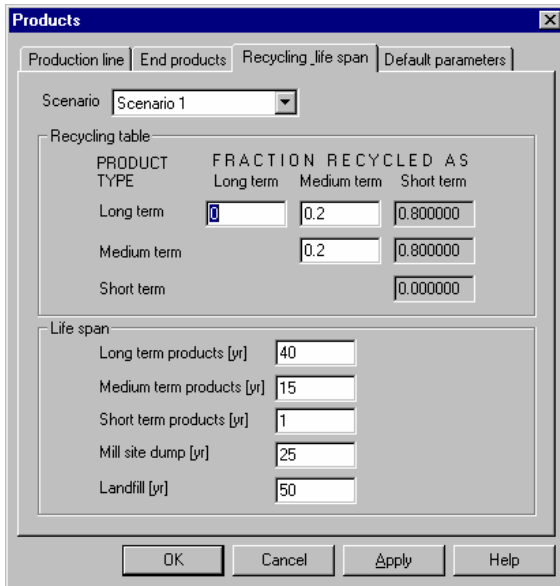


Figure 31. Parameterising the products module: way of recycling and life spans

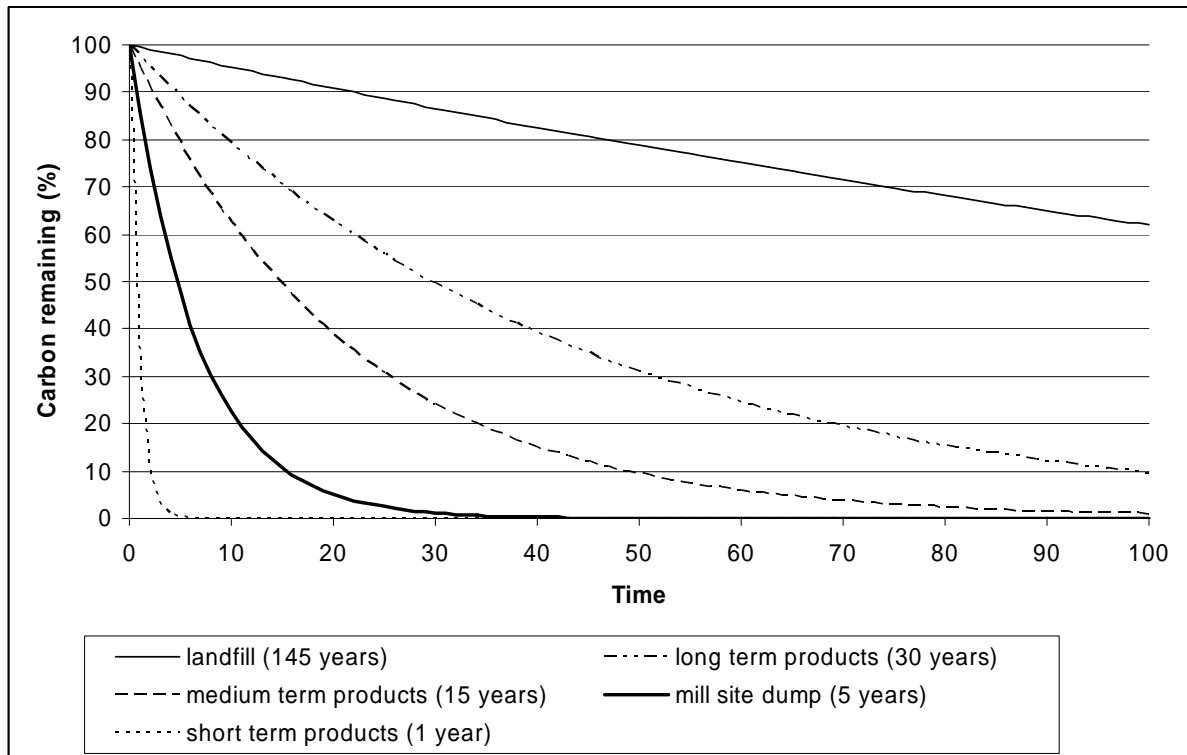


Figure 32. Discarding curves of carbon in end use products, mill site dump and landfill for their default half lives.

Default parameters

Under the *Default parameters* tab, two sets of default parameters can be loaded (Figure 33). 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.

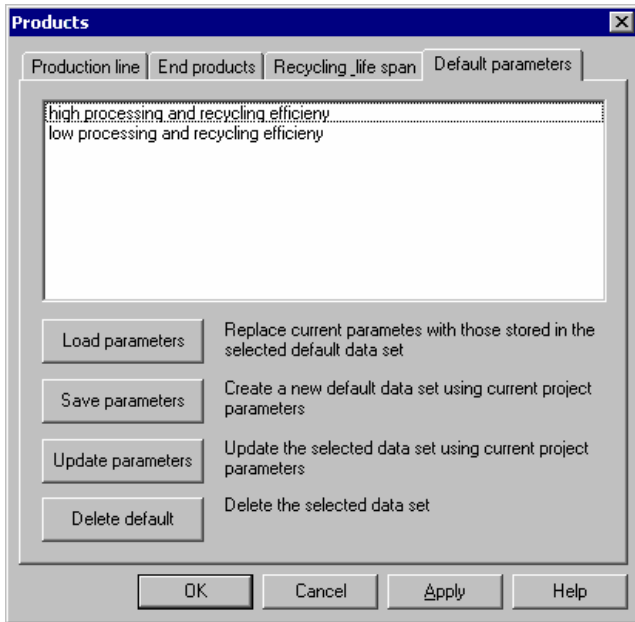


Figure 33. Parameterising the products module: choosing sets of parameters.

Bioenergy module

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.

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.

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 34)
- **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 34). If needed, these default values can be replaced by other values by the user.

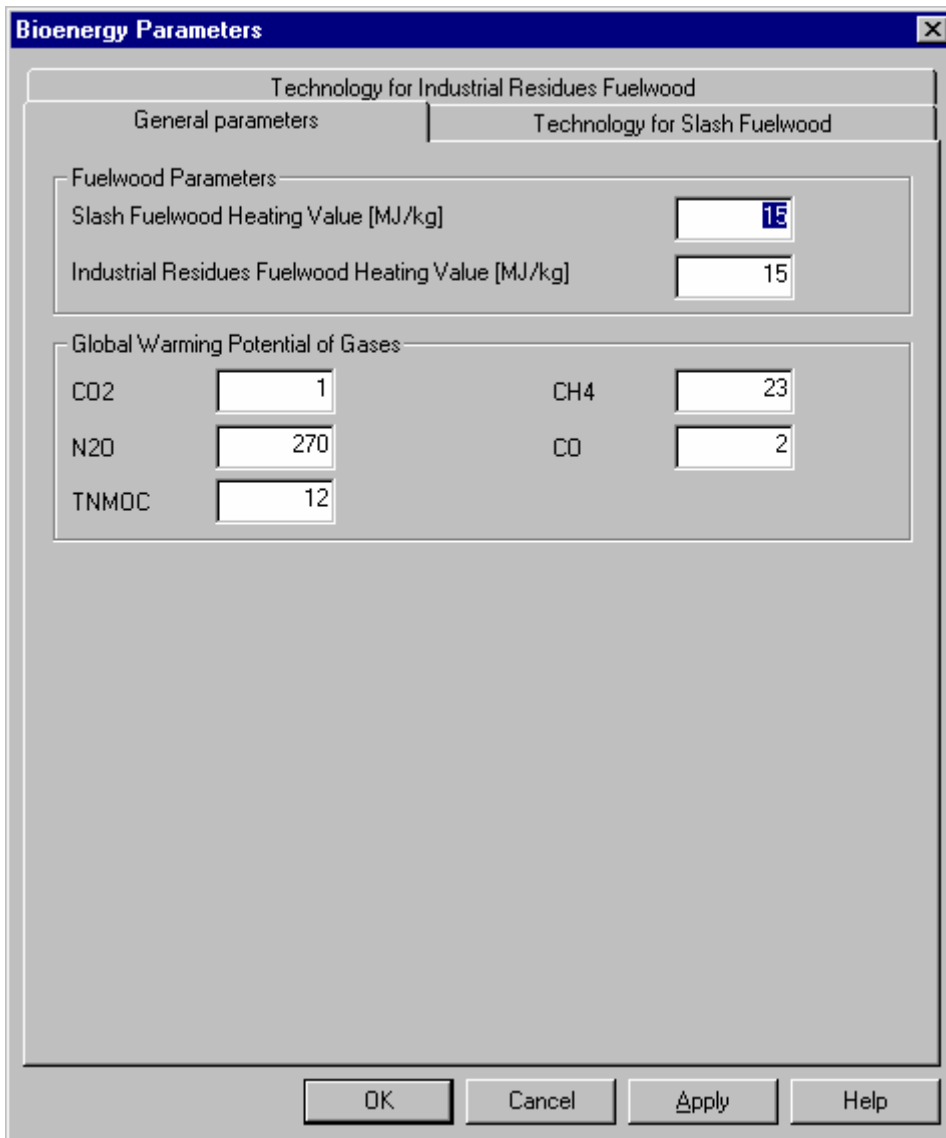


Figure 34: **General Parameters**

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 35).

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 36 and 37) 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.

Bioenergy Parameters

Technology for Industrial Residues Fuelwood

General parameters Technology for Slash Fuelwood

Scenario: Scenario 1

Fuel & Technology to be substituted

Fuel: Natural_Gas Heating Value (MJ/kg): 42.62

Technology: Cookstove Efficiency (%): 55

Technology Emission Factors (g/Kg fuel)

CO2: 3852.9332 CH4: 0.88010

N2O: 0.07842 CO: 0.0000

TNMOC: 0.0000

Choose...

Alternative Fuel & Technology

Technology: Improved Cookstove Efficiency (%): 25

Emission Factors (g/Kg fuel)

CO2: 0 CH4: 7.9200

N2O: 0.0600 CO: 69.5000

TNMOC: 6.8400

Choose...

OK Cancel Apply Help

Figure 35: *Technology for Slash Firewood*

Fuel & Technology to be substituted

Fuel: Natural_Gas Heating Value (MJ/kg): 42.62

Technology: Cookstove Efficiency (%): 55

Technology Emission Factors (g/Kg fuel)

CO2: 3852.9332 CH4: 0.88010

N2O: 0.07842 CO: 0.0000

TNMOC: 0.0000

OK Cancel

Figure 36: Selecting current fuel & technology

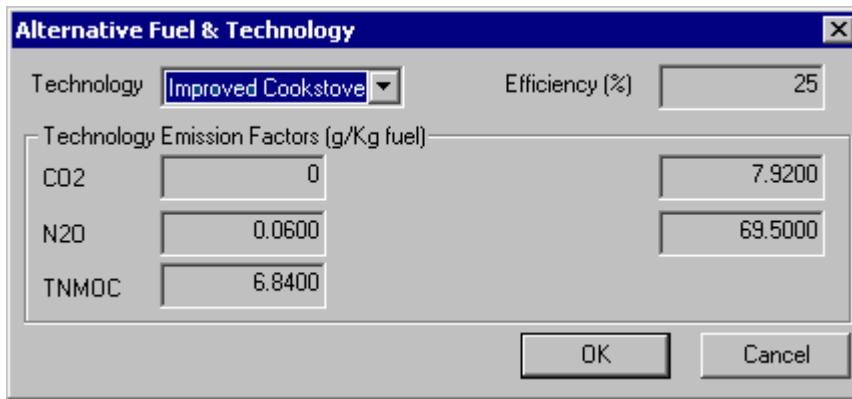


Figure 37: Selecting alternative fuel & technology

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.

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.

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.

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 38). 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.

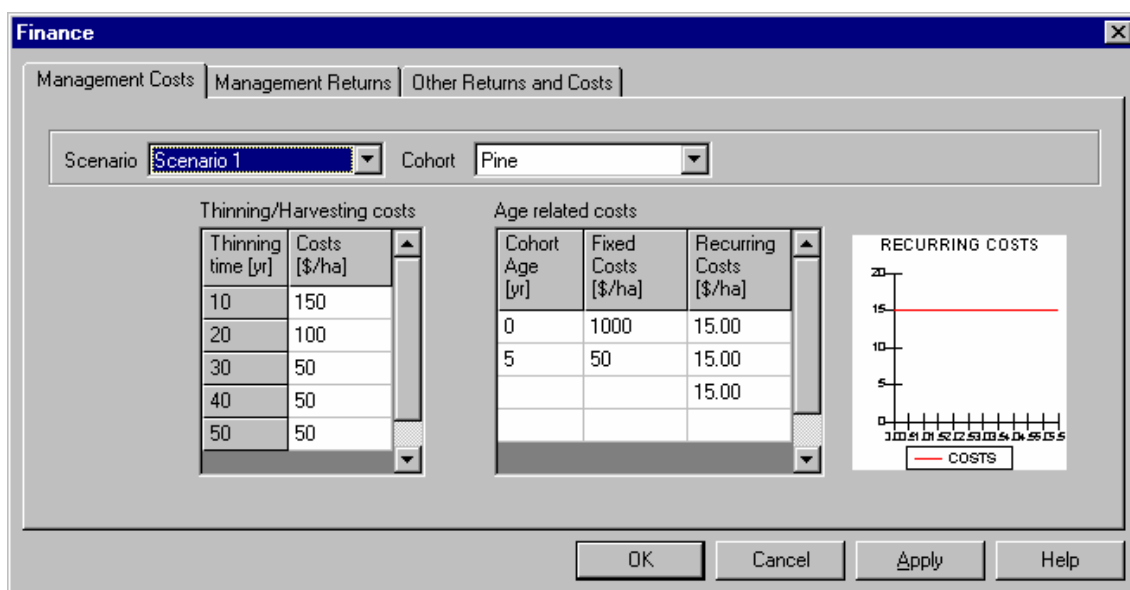


Figure 38. The parameterisation of the **Financial** module.

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 CO₂e) 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 **ICER** 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 ICER 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 ICER 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 ICERs is that tCERs are valid only until the end of the next commitment period, whereas ICERs are valid until the end of the crediting period. If the net sequestration is monotonically increasing then there are always credits being generated (Figure 39). 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 ICERs (Figure 40 and 41). The project proponent may decide to sell all ICERs issued, but may have to offer a discount for ICERs that will be reversed before the end of the crediting period (Figure 40). Alternatively, the project proponent may choose to retire (or not sell) the ICERs that would be reversed in the next period (Figure 41). 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 & ICERs

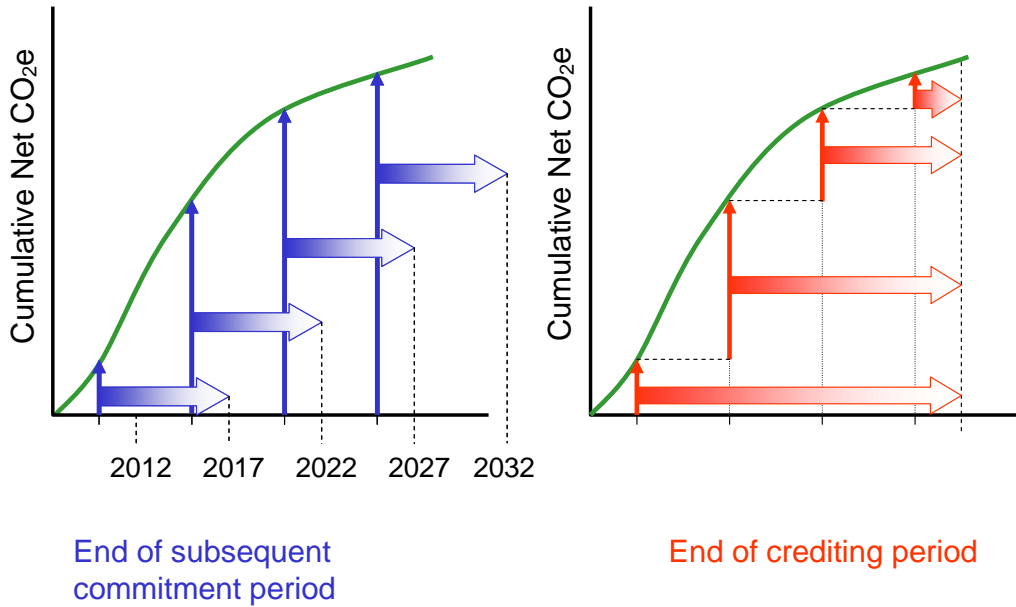


Figure 39. TCERs and ICERs in case of monotonically increasing carbon stocks (ENCOFOR 2004).

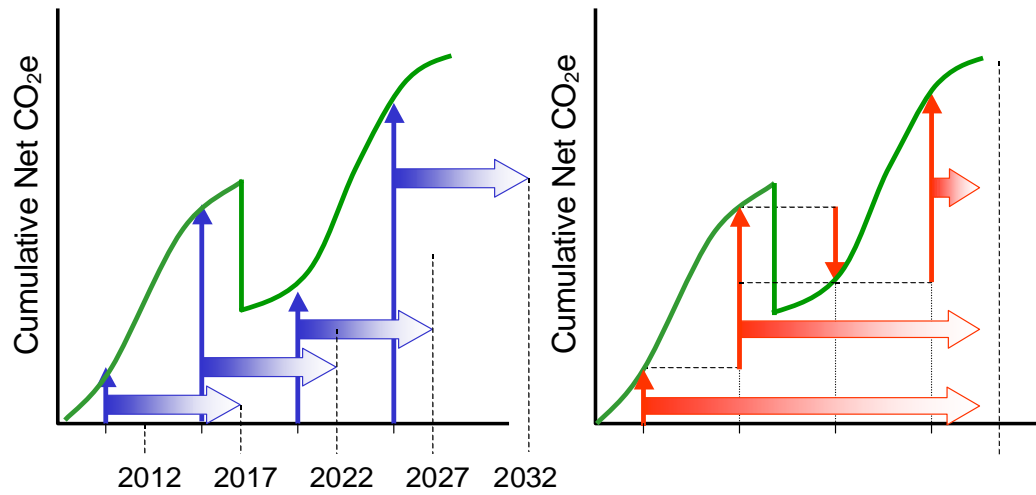


Figure 40. TCERs and ICERs in case of fluctuating carbon stocks, with reversal (ENCOFOR 2004).

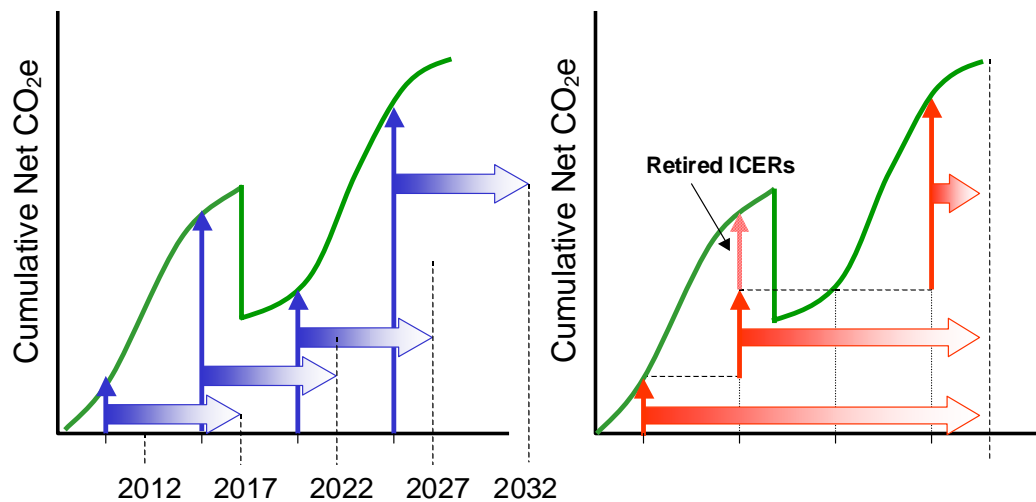


Figure 41. TCERs and ICERs in case of fluctuating carbon stocks, without reversal (ENCOFOR 2004).

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 42).

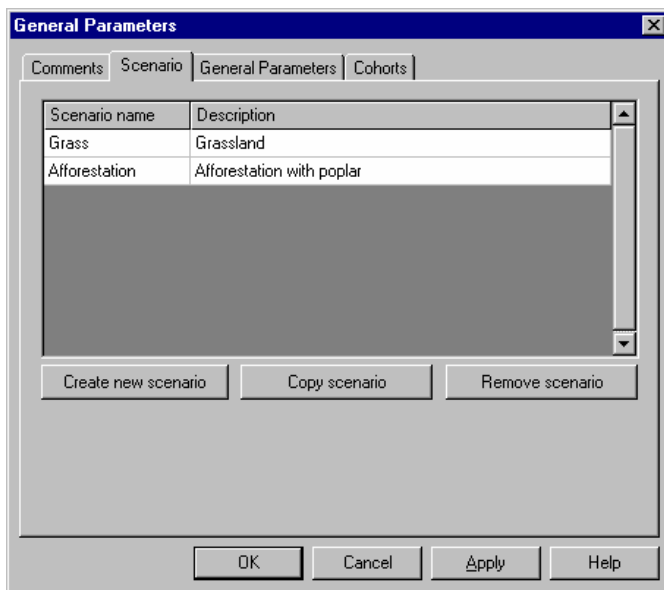


Figure 42. The definition of different scenarios.

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 43). 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.

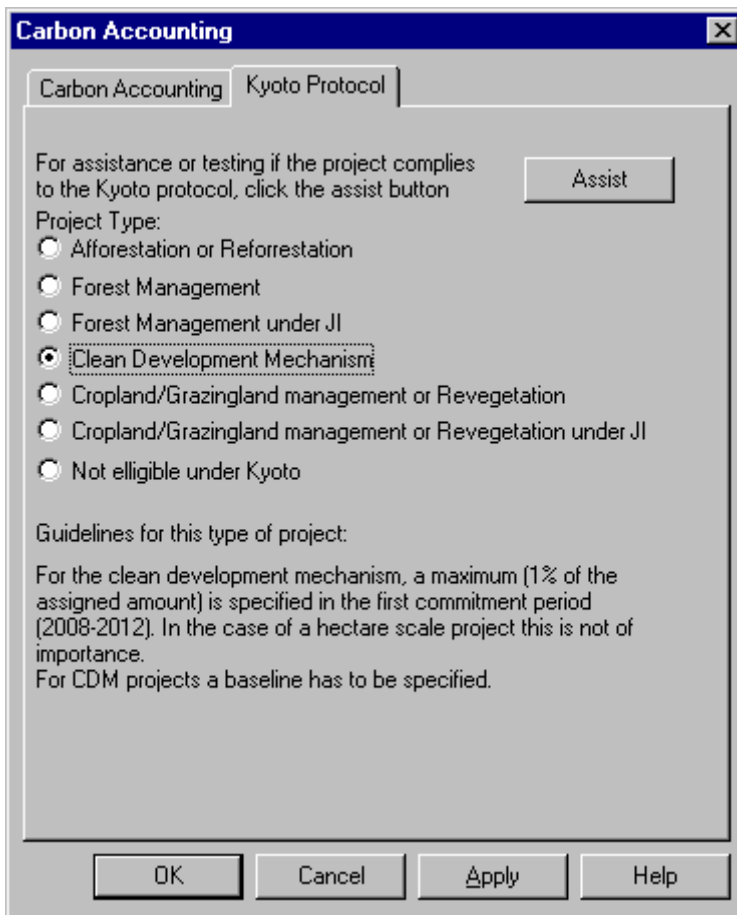


Figure 43. The *Kyoto Protocol* tab, showing the choice between different kinds of projects.

The first parameter in the *Carbon Accounting* tab is the *start year for crediting period* (Figure 44). 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 42), 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 28).

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 CO₂. Results of the bioenergy module are not taken into account. Within the crediting period, tCERs and ICERs (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 ICERs 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.

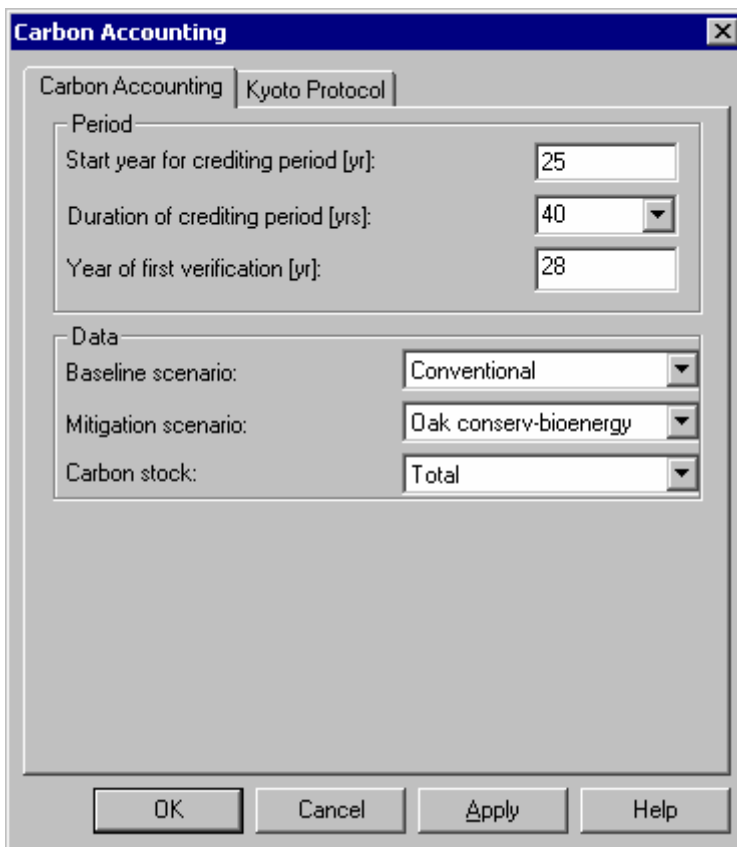


Figure 44. The parameters for carbon accounting.

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 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 45) can easily be altered through the 'view options' icon. A screen with the different options will appear (Figure 46). 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.

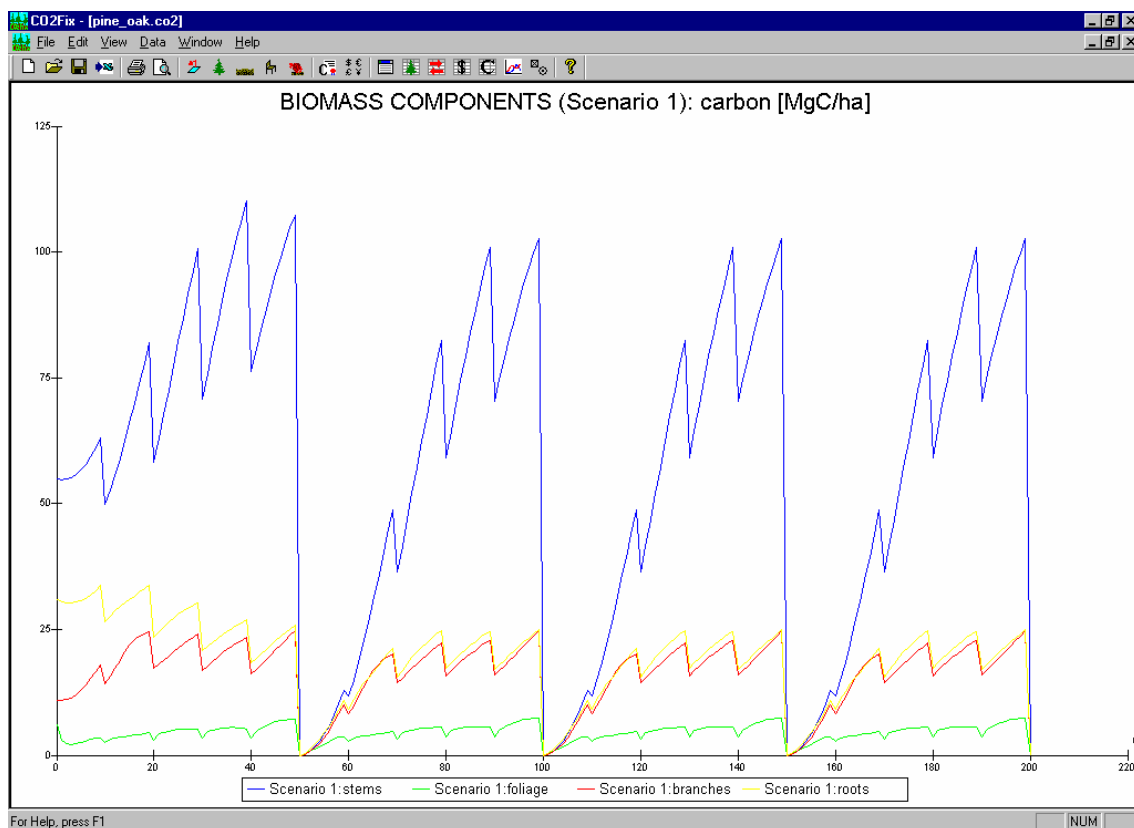


Figure 45. Example of a ready-made view option showing carbon stocks in each of the wood products compartments.

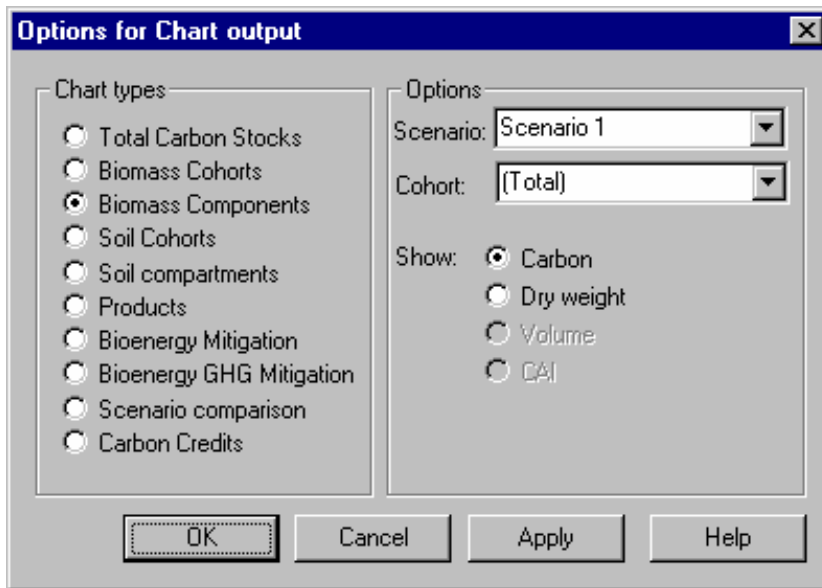


Figure 46. Options to change the content of the ready-made charts.

Examples

With the installation of the CO2FIX V 3.1 model, a couple of example files are installed in the Samples directory. 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 2 gives a summary of the examples, indicating their location, tree species and modules and approaches used. A short description is included here, a more elaborate description can be found in the description of the model, including references to studies where these examples have been used.

Table 2. 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

Managed Scots pine in The Netherlands

The files NL_Scots pine X.co2 cover a range of mono-species Scots pine stands in The Netherlands. Five growth classes are distinguished, based on the maximum mean annual increment (MAI) reached during a rotation. Increment is derived from yield tables (Jansen et al. 1996) and relative growth and turnover of other biomass compartments is calibrated against literature data. Growth is driven by age, and no mortality and competition are included, since this is supposed to be captured in the yield table. Thinnings are carried out every five years, following the yield table. Soil is parameterised to be in balance, although it is likely that the degraded sandy soils are still accumulating carbon. Financial data have been calculated using normative cost data from the Dutch State Forest Service and financial results of forest enterprises in The Netherlands.

Managed Scots pine and Norway spruce stands in Southern Finland

The files Fin_Scots pine.co2 and Fin_Norway spruce.co2 contain examples of managed Scots pine (*Pinus sylvestris* at *Vaccinium* site type) and Norway spruce (*Picea abies* at *Myrtillus* site type) stands in Southern Finland. Increment was taken from local growth and yield tables (Koivisto 1959). Relative growth and turnover of other biomass compartments was calibrated against literature. Thinning regimes were taken from national guidelines for forest management and no natural mortality, competition or management mortality was assumed in these examples. We assumed that 60 % of harvest residues from the final harvests of Norway spruce stands were utilised as bio-energy. Industrial residues from both Norway spruce and Scots pine were assumed to be utilised as bio-energy, since in Finland the process waste of forest industries is actually the biggest domestic source of energy. Process losses were determined from literature. Costs and revenues of forest management were derived from the Finnish Statistical Yearbook of Forestry 2001 (FFRI 2002).

Robinia 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. Products are excluded from the carbon calculations. Because this is a JI project (carbon credits are purchased by the prototype carbon fund) a base line is required. This baseline consists of degrading grassland. 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. This case, as well as the following three, is used in the paper by Groen et al. (in prep.).

Forest Management in Central Europe

The file Central Europe_FM.co2 is based on a case presented earlier by Nabuurs and Mohren (1993) and Maser 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. Competition between the cohorts is taken into account. Products are excluded from the carbon calculations. Because it is a regular forest management project, no baseline is needed.

Reduced impact logging (RIL) under the Clean Development Mechanism (CDM RIL)

The file Central_America_CDM_RIL.co2 contains a CDM case for a lowland wet tropical rainforest in Central America. The baseline is conventional (heavy) logging followed by further degradation, Reduced Impact Logging (RIL) is the mitigation scenario. RIL is not eligible under the CDM yet, but may be accepted in the future. Four cohorts are distinguished, with an important role for competition. Growth is specified in relation to standing biomass. On average a higher roadside price for wood from the RIL project is expected because less wood is damaged. However, in case of RIL, there is a loss due to missed logging revenues. Harvesting costs are rather high, because roadside prices are used. No other costs or returns are expected.

Afforestation with native species 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. The baseline is a pasture, with grass NPP of 10 ton 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 project scenario assumes an active reforestation with native species, for which the same cohorts and growth rates are used as in the CDM RIL case. No harvesting is carried out; the forest is left to its natural dynamics with some 2 to 3% natural mortality per year. Costs data are based on literature.

Pine-Oak Central Mexico

The file Central_Mexico_pine_oak.co2 is a case 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.). 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. Pine is managed in 50-year cycles and 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 oak removal is reduced. 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.

Teak plantation Costa Rica

The example 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 $15 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ over the rotation of 40 years. Thinning takes place at ages 3, 10, 20, and 30 years.

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).

Lowland dipterocarp forests at Kalimantan, Indonesia

The files Ind_dipt_primary forest_protected.co2, Ind_dipt_primary forest_logged.co2 and Ind_dipt_secondary forest.co2 show three cases of lowland dipterocarp forests at Kalimantan, Indonesia. Data were obtained from the Malinau Research Forest, supplemented with literature data. The generally 150-250 tree species per hectare were categorised in 6 cohorts according to common growth characteristics and common use of the different tree species. The file Ind_dipt_primary forest_protected.co2 shows a protected primary forest, where no harvesting takes place. The file Ind_dipt_primary forest_logged.co2 simulates the same forest, with a harvest every 35-year, followed by management mortality. The file Ind_dipt_secondary forest.co2 shows a forest that has been degraded by harvesting activities, which expresses itself in a lower biomass of all species, especially the commercial ones. Because of the lack of commercial species, this forest is not logged anymore.

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