

Work Package 1 – Shared modelling framework and learnings

D1.2 – Description of scientific methods

Task 1.2 – Foreground LCI

Tutorial for dynamic carbon flux modelling of forest plantation

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This document is a part of the ALIGNED project (grant no. 101059430) deliverable D1.2. It contains the description of, and instructions to use the Carbon Flux Model tool.

PROJECTS DETAILS			
Project title		Aligning Life Cycle Assessment methods and bio-based sectors for improved environmental performance.	
Project acronym	ALIGNED	Start / Duration	01/10/2022 – 36 months
Type of Action	RIA	Website	www.alignedproject.eu

DELIVERABLE DETAILS			
Dissemination level	Public	Nature	Report
Due date (M)	M18 (March/2024)	Submission date	31/03/2024

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DOCUMENT HISTORY			
Date	Version	Name	Changes
28/08/2023	0.1	Tutorial for dynamic carbon flux modelling of forest plantation	First draft
01/02/2024	0.2	Tutorial for dynamic carbon flux modelling of forest plantation	Extensive rewrite due to changes in the described model and updated data
28/02/2024	1.0	Tutorial for dynamic carbon flux modelling of forest plantation	Final revisions and formatting

TABLE OF CONTENTS

List of Figures	3
1. Executive summary	5
1.1. The output of the model.....	5
1.2. Summary of actionable steps.....	6
3. Description of Carbon flux model.....	7
4. User manual of the Carbon flux model.....	8
a. User input.....	8
i. General Parameters for Specific Wood Type	8
ii. Thinning operations	9
iii. Other sections.....	9
iv. Time reference for GWP and GTP.....	11
b. Calculation sheets.....	11
c. Results sheets.....	11
5. Export to SimaPro-csv format	11
References.....	14

List of Figures

Figure 1 General Parameters, where the green cells are for user-input fields within the model.....	10
Figure 2 Example of thinning practice and operations fields	10

Acronyms and abbreviations

ABBREVIATIONS	Description
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life Cycle Impact Assessment
GWP	Global Warming Potential
GTP	Global Temperature Potential
BCEFs	Biomass Conversion and Expansion Factor
S1	Species 1
S2	Species 2

1. Executive summary

This tutorial serves as a tool for users seeking to simulate carbon flux modelling of a forest plantation based on the work by De Rosa et al., 2017. If more information regarding the carbon flux modelling is needed, refer to the following articles: De Rosa et al., 2018; and De Rosa et al., 2017.

1.1. The output of the model

The Carbon Flux model generates a time-dependent carbon account, Global Warming Potential (GWP), and Global Temperature Potential (GTP) metrics, as well as the aggregated LCI of the production of wood from a user-specified plantation scenario.

- The aggregated LCI contains several processes (e.g., round wood production, sawn wood production, disposal) that can be linked to a larger product system to perform an LCA, and accounts for the substitution of products from a short-rotation plantation. *For example*, the sawn wood process generated by the Carbon Flux model can be linked as an input in LCA software to a process that uses sawn wood as a material. This new sawn wood process includes the linkages to the round wood production and disposal, and the carbon flows associated with them.
- To extract the data about dynamic carbon stock in the plantation(s) during the time horizon, refer to the "Calc_Balance_S1" and "Calc_Balance_S2" sheets, where the carbon uptake and emission flows are provided in yearly steps.
- For data about the time-dependent GWP and GTP characterized climate impact metrics, refer to the "Calc_GWP" and "Calc_GTP" sheets, where the appropriate characterization factors are applied to the carbon stocks over the time horizon in yearly steps.

The tutorial includes:

- Description of the woody biomass data, in the "Dataset-overview-of-biomass.xlsx" file
- Guidance to use the "LCA-carbonflux-emissions.xlsx" tool: This file contains the dynamic carbon flux model, including sheets for modelling inventories, selected biomass data, and a table format for exporting the LCI to LCA software.

1.2. Summary of actionable steps

Summary of steps :

1. *(Optional)* Add species/scenario to the biomass data sheet
2. **Choose S1 from the drop-down list**
3. *(Optional)* Enter thinning practice parameters
4. *(Optional)* Specify parameters of S2
5. **Choose an appropriate Time Horizon (default: 100 years)**
6. *(Optional)* Adjust calculation parameters to the specific case
7. **See foreground LCI for aggregated results**
8. *(Optional)* Export LCI to brightway2 and/or SimaPro

The following tutorial provides detailed instructions and explanations for these steps.

2. Description of the biomass data

Cf. file *ALIGNED-T1.2-dataset-overview-of-biomass.xlsx* in the T1.2 repository

This database is a compilation of specific data points related to various types of trees, sourced from reputable references that are cited within the file. The file consists of three separate sheets:

- "ReadMe,"
- "Dataset Overview",
- "Global Data"

The "ReadMe" sheet provides a description of the data contained in the file, including the description of all headings and columns.

The "Dataset overview" sheet contains all references, and documentation of all assumptions and generalizations, allowing users to trace the original source of each data point.

The "Global Data" sheet contains a table with all relevant data points necessary to set up the calculations in the Carbon Flux model for several species and locations, and some additional, supporting data that is used for assigning correct or appropriate values for the necessary parameters.

Where species and location-specific information was not available, data gaps were filled by using assumptions, averages, and blanket categories. For example, the data related to the "share of above ground slashes and woody debris harvested" have limited data points due to lack of accessible credible sources, and such is assumed to be the same across all species. Similarly, where reported "Rotation Time" data was not found, 100-120 years (Johannsen 2019), or 60-70 years (Johannsen 2019) were applied for the angiosperm and gymnosperm clades respectively, based on the default values from an early version of the dataset. A similar approach was applied to the "Biomass Annual Increment" and "Carbon factor", and "BCEFs" data columns as well. All assumptions are recorded in the "Dataset Overview" sheet; refer to that to decide whether the data is accurate enough for the desired modelling scenario.

3. Description of Carbon flux model

Cf. file: *ALIGNED-T1.2-LCA-Carbon-Flux-model.xlsx* in the T1.2 repository

The file *ALIGNED-T1.2-LCA-Carbon-Flux-model.xlsx* in the T1.2 repository serves as the primary tool for performing the dynamic forest carbon flux calculations, such as modelling biomass growth, woody decomposition, and obtaining mass balance growth, annual inventory of CO₂ fluxes, environmental impact from sawmilling, dynamic Global Warming

Potential (GWP) factors, and dynamic Global Temperature Potential (GTP) factors. Additionally, the tool provides a Life Cycle Inventory (LCI) in both volume and weight-based units, and an LCI table that is compatible with conversion methods into SimaPro-csv or Brightway2-dictionary formats for performing LCIA calculations. This tool enables users to obtain indicative insights into the production of forest biomass.

Disclaimer: it should be noted that the model has not been validated for all species and plantation types that can be modelled using the database. Validation with third-party information (real world measurements, results from other models, literature data) is recommended.

Within the *ALIGNED-LCA-Carbon-Flux-model-AAU.xlsx* file, the sheet titled "Biomass data" contains a copy of the "Global data" sheet of the *ALIGNED-dataset-overview-of-biomass-AAU.xlsx* file. This serves as input data for the model.

4. User manual of the Carbon flux model

Cf. file: *ALIGNED-T1.2-LCA-Carbon-Flux-model.xlsx* in the T1.2 repository

a. User input

The "Input Parameters" sheet comprises of seven sections. Within these sections, certain cells are highlighted in green, serving as user-input fields, while the remaining white cells are automatically calculated based on the input in the green cells.

i. General Parameters for Specific Wood Type

The "General Parameters for Specific Wood Type" section (**Figure 1**) allows for the inclusion of data for two distinct types of species. "S1" denotes the main species, while "S2" denotes a substituted species to account for the effect of by-products of the system.

For the primary species (S1), the user can choose the "Wood type" from the drop-down list in the first row of the "Value S1" column and enter a desired Time Horizon (100 years is the default option). The table then automatically fill in the rest of the general parameters for that configuration, referring to the data in the "Biomass data" sheet.

If the desired species (or location) is not available in the drop-down list, the user may choose the "_default (Spruce)" option, which fills in the fields with the original data from De Rosa et al., 2017. Alternatively, the user may choose to:

- create a new data line in the "Biomass data" sheet. If the new line is inserted before the "_Default (Spruce) ()" entry, the data validation field in the "Input parameters" must be expanded to include the new information.
- replace the functions in the relevant fields of the "General Parameters[...]" with specific data for their scenario. In this case, the links between this field and the "Biomass data" table will be broken, which does not affect the calculation processes or the results but prevents future automatic "load-in" of biomass data.

ii. Thinning operations

The "Thinning Operations" section (**Figure 2**) is automatically updated based on the rotation time and a generalized thinning practice. The tool assumes by default that plantations under 30 years undergo one, plantations under 70 years undergo two, and plantations with a longer rotation time undergo three thinning operations, with 30%, 20%, and 10% intensity progressively. This is recorded in the "S1 Thinning practice" section of the input sheet. If a different thinning practice is to be modelled, the user has two options:

- a) The "S1 Thinning practice" section may be adjusted by changing the thinning ages or intensities. In this case, the formula in the "Species 1 Thinning operations" section (column J) should be checked and expanded if needed.
- b) Manually override the "Thin. Intensity" in the "Species 1 Thinning operations" section (column J)

It is important to note that the model records the thinning intensity as a share of the total growing biomass volume. If the user wishes to specify a different thinning intensity, it should be checked whether their thinning intensity data is recorded as share of basal area, relative stand density, or share of biomass volume, and necessary adjustments should be made.

The secondary species (S2) can be also configured by the user for their specific scenario. S2 is intended to be modelled as a short-rotation species, such as the default example of Eucalyptus. As the model is designed to simulate a relationship between the two plantations in which by-products of the S1 timber production substitute the output of the S2 plantation, it is important that S2 is a non-timber producing plantation without co-products. A species that is likely to be substituted by the S1 should be used.

iii. Other sections

Other sections on this sheet (e.g., "Switch 1", "Switch 2", etc.) are pre-filled with the recommended default settings. However, users may replace these values with their specific case's information. It is recommended that the user refer to the original work by De Rosa et al. (2017) before performing changes to green cells in sections other than the "General parameters", "Thinning operations", and the "Thinning practice". Ensuring an understanding of the model and its implications is crucial prior to making any changes.

Figure 1 and *Figure 2* depict the input parameters for S1 and S2:

General Parameters for specific wood type						
Name	Description	Units	Value S1	References S1	Value S2	References S2
	Wood type	Choose from list:	Abies alba (Poland)	-	Eucalyptus	-
0	Time horizon	(y)	100		100	
1	Rotation time	(y)	115	FAO, 2005	6	-
2	Annual increment AG Biomass	(m ³ ha ⁻¹ y ⁻¹)	6,8	FAO, 2005	50	
3	Basic Wood Density (conversion factor m ₃ ->t)	(t dm m ⁻³)	0,35	Albers et al., 2019	0,51	IPCC (2006, table 4.13)
4	Carbon factor (C content in wood)	(t C t dm ⁻³)	0,48	Albers et al., 2019	0,49	IPCC (2006, table 4.3)
5	R(B.G./A.G.)	-	0,3	De Rosa et al., 2017	0,24	IPCC (2006, table 4.4)
6	BCEFS (biomass conversion and expansion factor: merchantable growing stock volume to above-ground biomass)	t dm m ⁻³ -1	0,7	IPCC 2006	0,66	IPCC (2006, table 4.5)
7	Share of above ground slashes and woody debris harvested	share	0,8	De Rosa et al., 2017	80%	-
8	Share of below ground woody debris harvested	share	0	De Rosa et al., 2017	0%	-

Figure 1 General Parameters, where the green cells are for user-input fields within the model

Species 1 Thinning operations			Species 2 Thinning operations			S1 Thinning practice:	
Year	Thin.	Intensity	Year	Thin.	Intensity	RT	
1		0%	1		0%	65,0	
2		0%	2		0%	y	1
3		0%	3		0%	22	0,3
4		0%	4		0%	43	0,2
5		0%	5		0%	0	0,0
6		0%	6		0%		
7		0%	7		0%		
8		0%	8		0%		
9		0%	9		0%		
10		0%	10		0%		
11		0%	11		0%		
12		0%	12		0%		
13		0%	13		0%		
14		0%	14		0%		
15		0%	15		0%		
16		0%	16		0%		
17		0%	17		0%		
18		0%	18		0%		
19		0%	19		0%		
20		0%	20		0%		
21		0%	21		0%		
22		30%	22		0%		
23		0%	23		0%		
24		0%	24		0%		
25		0%	25		0%		
26		0%	26		0%		
27		0%	27		0%		
28		0%	28		0%		
29		0%	29		0%		
30		0%	30		0%		
31		0%	31		0%		
32		0%	32		0%		
33		0%	33		0%		
34		0%	34		0%		
35		0%	35		0%		
36		0%	36		0%		
37		0%	37		0%		
38		0%	38		0%		
39		0%	39		0%		
40		0%	40		0%		
41		0%	41		0%		
42		0%	42		0%		
43		20%	43		0%		
44		0%	44		0%		
45		0%	45		0%		

Figure 2 Example of thinning practice and operations fields

iv. Time reference for GWP and GTP

It is important for the user to carefully determine the time reference for the influence of CO₂ their specific case. This is because CO₂ effects can be defined either by GWP (Global Warming Potential) and GTP (Global Temperature Potential). GWP quantifies the total heat absorbed over a specified time period resulting from gas emissions, while GTP measures the temperature change at the end of that time period due to gas emissions. Therefore, depending on the specific scope and context of the user's case, it can be decided whether GWP or GTP is most relevant for the case.

Both types of calculations are calculated within the model, specifically in the "Calc_GWP" sheet (for GWP) and "Calc_GTP" sheet (for GTP), and solely rely on the time horizon defined by the user in the "Input Parameters" sheet.

b. Calculation sheets

The following sheets, which require no user input, perform a series of calculations based on the values specified in the "Input_Parameters" sheet:

- Calc_Growth_S1
- Calc_Growth_S2
- Calc-Decomp_S1
- Calc-Decomp_S2
- Calc_Balance_S1
- Calc_Balance_S2
- Output_Balance_S1
- Output_Balance_S2
- Sawmill_Balance
- Calc_GWP
- Calc_GTP

c. Results sheets

The sheets "LCI (m³)", "LCI (ton)" and "csv_export" contain the aggregated LCI data for the entire life cycle in three different formats. The description of these sheets and the method for the biomass substitution between S1 and S2 is recorded on the "LCI - Explanation" sheet.

5. Export to SimaPro-csv format

After selecting or entering the desired settings on the "Input_Parameters" sheet, the generated "csv_export" sheet can be exported and converted into a SimaPro-compatible csv-file (SimaPro-csv) with a few additional steps. This process can also be completed manually by copying the processes and values from the LCI table, but with a basic knowledge of Python, this task can be automated by following these instructions:

- 1) First, check and ensure that the entries in the "Simapro name" column exactly replicate the nomenclature used in SimaPro. The SimaPro software will not recognize the product or substance if the naming convention lacks e.g., a space.
- 2) To convert the sheet into a SimaPro-compatible CSV format, please refer to the following link: <https://github.com/massimopizzol/aligned-converter>.

The link contains a comprehensive README that explains the conversion process, which requires Python and the Pandas library required to execute successfully. After installing these modules, follow the instructions provided in the guide, starting with saving a copy of the "csv_export" sheet from the Excel file as a separate CSV file, which then can be restructured and converted by the provided script into another, SimaPro-compatible CSV file that can be imported into SimaPro.

- 3) In SimaPro, ensure that the correct libraries (e.g. 'Ecoinvent 3 - consequential - unit' and 'Methods') are selected in "Libraries" underneath "Goal and scope". Moreover, when importing "csv_export", ensure that under "Object link method" that 'Try to link imported objects to existing objects first' is selected.

There are additional considerations to make, before the user uploads the data into SimaPro:

- The choice of background datasets linked to the foreground system can substantially impact the results of the Carbon Flux Model. On the sheet "LCI - Explanation" an overview of the selected datasets from ecoinvent is provided. These datasets include data from the scale from Global World (GLO), Rest of the world (meaning entire world without China) (RER) and data only related to Sweden (SE). These are chosen to enable a general and broad baseline for any analysis, but modifying any of these can influence on the results. Moreover, also changing the different types of technologies, fuels and more within the background will also influence the overall Carbon Flux model.
- Specifying the type of carbon emission for import in LCA software. While the model can return estimates of Carbon Dioxide flows and respective time-adjusted global warming impact estimates, these estimates need to then be imported in LCA software that does not usually allow to include time-specific emission flows, or does it in a way that is rather impractical. Here some important notes for using the model:
 - Aggregated values: values in the final inventory are reported as aggregated. This means that the time-dependent emissions have been integrated over time and only the integral (or discrete sum in this case) is reported. This means that the value of carbon dioxide is the total value aggregated over the emission period, (it is not the instantaneous value at a specific year).
 - Choice of exchange name. In the sheet "csv_export" three exchange names are used.
 - "Carbon dioxide, biogenic (GWP-time)" and Carbon dioxide, in air (GWP-time) this will be imported as a new (foreground) exchange and reports the aggregated value of characterized impact for the GWP indicator. If one wants to use this alongside the other emissions from the database, the user has to either
 - Change the name into the name of an existing environmental exchange (e.g. "Carbon Dioxide, Biogenic")

- Or modify the LCIA method to include a characterization factor of value 1 for this exchange in the desired climate change impact category.
 - “Carbon dioxide, biogenic (GTP-time)” and “Carbon dioxide, in air (GTP-time)”. Same as in the previous case but with GTP instead of GWP.
 - “Carbon dioxide, fossil”. Differently from the two previous cases, these are the raw inventory flows (not the characterized ones) aggregated over the time-period. Since these are inventory level flows and not characterized results, there is no “discounting” due to time factors. These values can thus be used to check for mass balances. The use of the exchange name “fossil” is to ensure that these emissions are accounted with a characterization factor of one.
- Depending on the use of the model, the user must consider one of the carbon dioxide exchanges provided and remove the other ones to avoid double counting.
- It is not possible to provide a “one-fit-all” solution. Inevitably the way the dynamic emissions are included in the model is user specific and specific tailoring to each case will be needed. The model allows to simulate a wide range of options and the choice of specific option and subsequent model adaptation is left to the user.

References

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