

# Work Package 1 – Shared modelling framework and learnings

D1.2 – Description of scientific methods

## Overview of deliverable and associated documents

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This document is the ALIGNED project (grant no. 101059430) deliverable D1.2. It contains a summary of scientific methods and best existing and new developed science-based practices for LCA studies in the bio-based sector.

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# Acronyms and abbreviations

ABBREVIATIONS	Description
<b>WP</b>	Work Package
<b>LCA</b>	Life Cycle Assessment
<b>LCI</b>	Life Cycle Inventory
<b>LCIA</b>	Life Cycle Impact Assessment
<b>CC</b>	Climate Change
<b>CF</b>	Characterisation Factor
<b>GWP</b>	Global Warming Potential
<b>GTP</b>	Global Temperature Potential
<b>GHG</b>	Greenhouse Gas
<b>GLAD</b>	Global LCA Data Access network
<b>TEA</b>	Techno-economic assessment

## Executive summary

The deliverable D1.2 “Description of scientific methods” proposes a scientific framework for the life cycle assessment of biobased products in the ALIGNED project and more broadly to improve the environmental performance of bio-based industrial activities in five sectors: construction, woodworking, textiles, pulp and paper and chemicals.

The scientific framework includes approaches, methods, and tools, developed within WP1 of the ALIGNED project and respective tasks, in particular:

- A method for generating dynamic background systems for prospective LCA. Linked to task T1.1 *Framework for background life cycle inventory of bio-based sectors*.
- A method for identification of market constraints: geographical, production capacity, co-production, and policy. A method for time and space-dependent carbon accounting in bio-based carbon uptake and release activities able to return mass balanced carbon inventories. Linked to task T1.2 *Framework for foreground life cycle inventory of bio-based sectors*.
- Methods and characterization factors for dynamic assessment of climate change and assessment of biodiversity impacts. Linked to task T1.3 *Framework for Life Cycle Impact Assessment (LCIA)*.
- Methods for uncertainty and sensitivity analysis in bio-based sectors. Linked to task T1.4 *Framework for interpreting uncertainty*.
- A method for socio-economic assessment in bio-based sectors. Linked to task T1.5 *Framework for socio-economic assessment*.

The deliverable consists of a series of documents such as guidelines, routines, algorithms, datasets, models, spreadsheets, calculators, codes, and notebooks - all available in open access task-specific project repositories.

This document describes the specific purpose and associated content of each part of the methodological framework and provides thus an overview and map for understanding and navigating the material associated with the deliverable D1.2.

## Introduction

WP1 of the ALIGNED project intends to provide a sound scientific framework For conducting **Life Cycle Assessment (LCA) of biobased products** within the five industries within the scope of the project: construction, woodworking, textiles, pulp and paper, and chemicals.

The objective of WP1 is to strengthen the scientific basis of LCA in the bio-based sectors by **aligning** practices, overcoming limitations, and establishing a common framework for all LCAs in the project, making it easier for bio-based industry practitioners to carry out comprehensive and scientifically sound LCAs.

The idea is to make **openly available and operational** system of advanced LCA approaches, methods, models, and tools to support bio-based industries in the assessment of what sustainable production processes are, and testing the effectiveness and validity of such system on the project case studies to extract shared learnings and insights by critically assessing their implementation within and across five bio-based sectors.

Thus, **the ALIGNED scientific framework comprises a system of approaches, methods, models, and tools** that can all be applied in biobased industries and across sectors. To materialize this framework into a deliverable, it is not sufficient to provide a single document but a series of documents of different types need to be provided, along with recommendations for the application of the framework by various types of users.

The material of D1.2 includes an **overview guide** (this document) and a series of 6 repositories, containing documents of different kinds: from guidelines in pdf, to spreadsheets and codes in text format. Figure 1 below illustrates how the material is organized.

The common thread throughout the deliverable is the **“tiered approach”**. Each guideline provides recommendations for practitioners on how to use the methods using different tiers, typically three. The lowest tier (tier 1) is the recommendation for a basic use of the methods that ensures greatest applicability, lowest complexity, but also lowest accuracy. The target audience is usually users with limited resources (time, knowledge, expertise) to perform a more advanced analysis. The highest tier (tier 3) is the recommendation for an advanced use of the methods, ensuring the highest accuracy but also involving higher complexity compared to the low tiers and is targeting an audience of users with substantial resources available who are interested in a very thorough analysis.

In the ALIGNED project the methods presented in this guide will be further applied in the case studies of WPs2-6 and WP9. The application on the case studies will allow us to derive insights and learnings on the methods’ applicability, added value, and operability across sectors, thereby further improving the methods and the scientific framework.

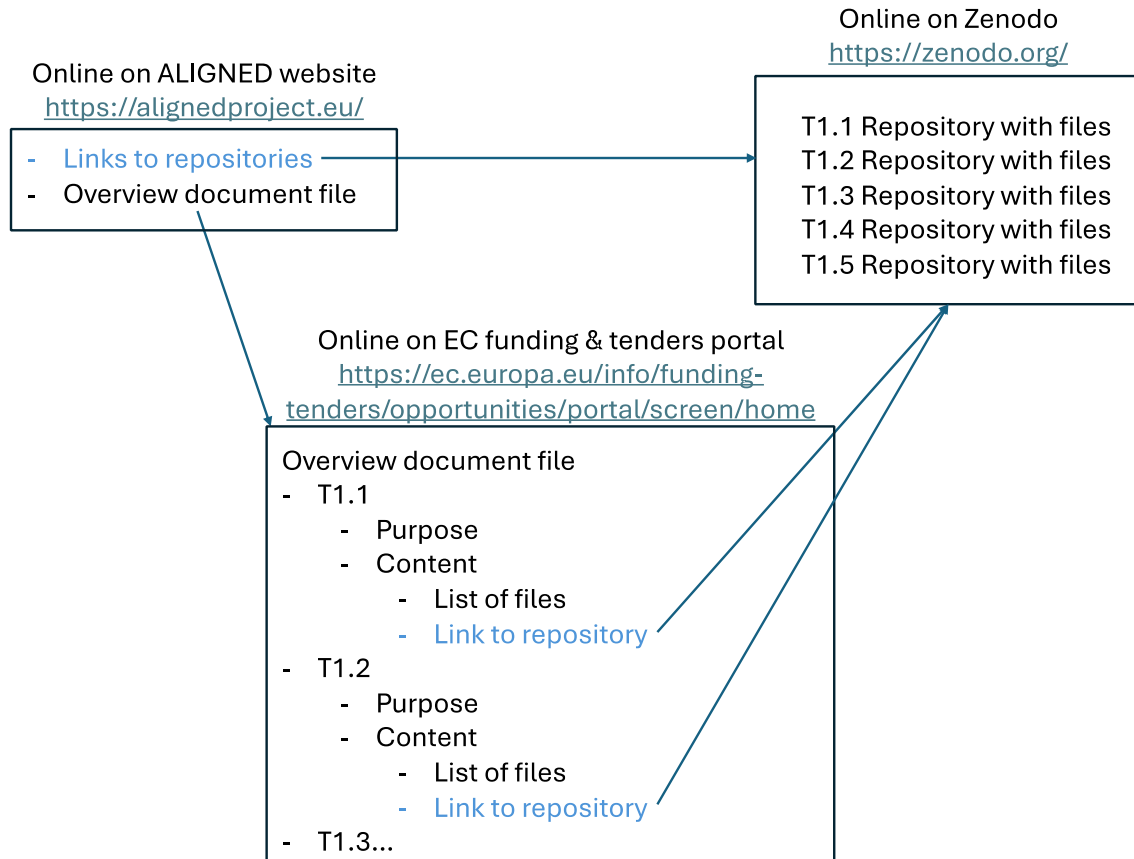


Figure 1 Structure of the Deliverable D1.2 and the associated documents and repositories.

# 1. Methods for background life cycle inventory

## 1.1 Description of purpose

It is an advanced, flexible, future-oriented, and multi-regional LCA inventory model. The model sets the basis for modifying current background database both for attributional and consequential LCAs through tutorials and codes that can be used by the partners and LCA stakeholders in general.

The method can be applied to perform prospective assessment in cases studies of the bio-based sector and beyond. The method provides specific guidance on modelling and generating future prospective versions of the background system, considering different levels of complexities and needs, which can vary according to the skills of practitioners when implementing prospective LCAs (Tiered approach). The output databases rely on the use of the LCA database ecoinvent and the software Premise, which will generate future databases compatible with both SimaPro and Brightway2 LCA software.

## 1.2 Description of content

The open-source model for background life cycle inventory of bio-based sectors consists of a set of documents, tutorials, and data templates:

- **Model description for background life cycle inventory of bio-based sectors**

The document consists of a brief description of the theoretical basis of prospective LCA and a tiered-based approach for generating background databases.

- **A tutorial for generating background life cycle inventories, Tier 1**

The document contains a tutorial for generating a single background database with an attributional approach.

- **A tutorial for generating background life cycle inventories, Tier 1**

The document contains a tutorial for generating a single background database with a consequential approach.

- **A tutorial for generating background life cycle inventories, Tier 2**

The document contains a tutorial for generating multiple background databases with an attributional approach.

- **A tutorial for generating background life cycle inventories, Tier 2**

The document contains a tutorial for generating multiple background databases with a consequential approach.

- **An example of the foreground inventory format to be modified by the user (an excel file)**

The example provides a template for compiling the users' own Brightway2 foreground inventories and connecting them to the users' prospective background databases by using a Jupyter notebook. More detailed instructions can be found in the Tier 2 tutorials.

- **Environment specifications (.yml file)**



The YAML source file contains the specifications for the environment used in the tutorials in Task 1.1.

DOI: 10.5281/zenodo.10842988

[Link to the repository](#)

## 2. Methods for foreground life cycle inventory

### 2.1 Description of purpose

The purpose of this task is to provide scientific evidence, tools and data to support the modelling choices considered in developing the foreground inventories of biobased products. There are two key factors that influence foreground modelling choices in relation to LCA of bio-based products or materials. First, the method for dynamic carbon accounting of forest plantation aims to improve the accounting for biogenic carbon flows from forest plantations. By providing year-to-year uptake and emission data, characterized dynamic GWP and GTP values, and an aggregated LCI, this tool allows LCA practitioners to incorporate time-dependent carbon flows from woody biomass for use in bio-based LCA processes. ALIGNED provides an open-source model, an accompanying tutorial for guidance and customization, an extensive database of tree species and management scenarios, as well as data and documentation of the model's validation process.

The second purpose of this task was to consider the increase in demand hence competition for biomass resources. This task proposes an open-source method for identification of market constraints which could be due to the multiple issues: geographical, production capacity, co-production, and policy. This method provides descriptive decision trees that can help practitioners identify if a resource is constrained and subsequently identify the modelling choices that must be considered. In addition, the method elaborates on recommendation to identify marginal suppliers of resources using production projections or historical trends. The method also includes comparisons of the best available datasets, routines and codes, which are available open access in project repository and algorithms documented in the guideline documents.

### 2.2 Description of content

Open - source method for identification of market constrains consists of following parts: method for dynamic carbon accounting for forest plantation, method for modelling competition for biomass, and method for structuring inventory data.

#### 2.2.1 Method for dynamic carbon accounting of forest plantation

- **Dataset overview of biomass**

A database in excel containing data to be used in the carbon flux model. The database includes appropriate values for the model input parameters for several different species and locations, allowing the user to choose or specify a setting most relevant for the feedstock they wish to model.

- **LCA Carbon Flux emissions calculations**

The Carbon Flux model is an Excel tool for modelling the life cycle inventory of a customizable forest plantation, including dynamic carbon stock calculations on a yearly basis. This consequential model takes into consideration the avoided products of a second, short rotation forest plantation. The model outputs can be used in a dynamic LCA of a

product using wood as an input, or in a static LCA model, for example in SimaPro or brightway2.

- **A tutorial for dynamic carbon flux modelling of forest plantation**

A tutorial for using LCA Carbon Flux emissions calculations model and exporting its results to different LCA software-compatible formats. The tutorial explains the main components of the Carbon Flux model, provides instructions for selecting values from the available scenarios, and offers guidance for more advanced users to tailor the inputs for a better fit to their specific case. Additionally, it contains basic instructions for using the model output in LCA projects and includes links to the Python script for an automated conversion process to different formats.

- **Carbon Flux model validation data**

A spreadsheet containing all data used for the validation process.

- **Carbon Flux model validation**

A documentation of the Carbon Flux model validation process, including the description of the methods for validation, justification for assumptions and data manipulation, the results yielded by the process, and interpretation of these results.

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[Link to the repository](#)

### 2.2.2. Method for addressing competition for biomass

- **Method for modelling constraints to biomass availability**

The document presents a method for modeling constraints to biomass availability under various circumstances. First, it provides a theoretical introduction to how the problem is approached from a consequential perspective. Furthermore, specific recommendations are provided for modelling the supply of biomass in line with this theory and indications for which types of data to use with respect to the methodological choices are provided.

- **Screening and comparison of data sources to calculate market mix**

The document presents screening of potentially useful literature and data sources as basis for modelling, a market mix of unconstrained suppliers of biomass feedstocks, as well as a comparison of the data from three selected sources, that showed poor agreement. Based on the screening of the literature and on the analysis, the FAOSTAT data is recommended for calculating a market mix of unconstrained suppliers for use in the LCAs of the ALIGNED project.

- **Comparison of data sources (.xlsx file)**

Spreadsheet with data and calculations on which the above-mentioned screening and comparison of data sources to calculate market mix is based.

- **Modelling a market mix from FAOSTAT data**

This tutorial serves as a tool for users seeking to model a market mix for selected biomass products, starting from the Forestry Production and Trade data from FAOSTAT. By utilizing the tutorial, the user can generate overviews of annual production quantity of biomass for different countries.

- **Code for implementation of calculations for marginal mix (.xlsx, .py, .jpybnb and .R files)**

Models and code to implement the calculations described in the guideline to calculate a marginal mix starting from FAOSTAT data. Coding is provided in both Excel, R, and Python for different users.

- **Datasets used for market mix calculation analyses (.csv files)**

Raw data from FAOSTAT to be used in the example for market mix calculation analyses.

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[Link to repository](#)

### 2.2.3. Method for structuring Life Cycle Inventory data

- **Guide for structuring and sharing LCI data**

Document provides step-by-step procedure to compile LCI inventory documentation in ALIGNED.

- **Explainer to understanding the ALIGNED LCI data template**

This document includes slides explaining the template used to organize foreground LCI in the ALIGNED project.

- **ALIGNED LCI template (.xlsx file)**

This document contains an empty template to be used for new data.

- **ALIGNED LCI template example with data (.xlsx file and .csv files)**

ALIGNED LCI template filled in with data that can be used as an illustrative example.

- **GLAD metadata template (.xlsx file)**

This document is an empty template with all the recommended GLAD metadata, to be used for documenting new LCI datasets.

- **Data import notebook (.ipynb and html files)**

Python language notebook that shows import of LCI data into the brightway2 open source LCA software. The notebook is given both in .ipynb format for python users who want to use the notebook directly and in .html format for quick reading and for non python users.

- **Importer for life cycle inventory data (.py file)**

Specific python script used to import the data

DOI: 10.5281/zenodo.10843472

[Link to the repository](#)

## 3. Methods for Life Cycle Impact Assessment

### 3.1 Description of purpose

This task presents practical approaches to harmonize and apply the latest recommendations on the impacts assessment phase of LCAs within the ALIGNED project. It specifically addresses climate change and biodiversity impacts and provides ready-to-use characterization factors formatted for import into major LCA software. A synthesis of the latest research and existing climate change and biodiversity assessment frameworks tailored to LCA are provided. The sets of characterization factors, along with step-by-step tutorials – including import routines and calculation tools - to improve their usability are available in open access in the project repository. Linked to T1.3.

### 3.2 Description of content

- **Guide on the Life Cycle Impact Assessment (LCIA) for bio-based products – Climate change**

This document presents a synthesis of the latest research and existing climate change assessment frameworks tailored to LCA, and the corresponding ALIGNED guidance. The guidance covers the strategies to adopt to include dynamic carbon flows accounting in the LCIA phase and discusses the need to distinguish biogenic from fossil carbon when assessing climate change in LCAs. Period-specific characterization factors (CF) for Global Warming Potential (GWP) and Global Temperature Potential (GTP) for different time horizons are defined, compared and their implications discussed. As for each component of ALIGNED’s methodological framework, a guidance formulated as a tiered approach is proposed.

- **Guide on the Life Cycle Impact Assessment (LCIA) for bio-based products – Biodiversity**

This document presents a synthesis of the latest research and existing biodiversity impacts assessment frameworks tailored to LCA, and the corresponding ALIGNED guidance. The latest characterization factors related to impacts on biodiversity of the main greenhouse gas (GHG) emissions are made available for import in real case LCAs. As for each component of ALIGNED methodological framework, a guidance formulated as a tiered approach is proposed.

- **Tool for deriving dynamic characterization factors for climate change**

This Excel spreadsheet contains an estimation of year-specific characterization factors (CF) for GWP100 (both Levasseur and Ventura methods), GWP500, GTP50 and GTP100, along with the calculation of characterized score for time-distributed CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O inventories. Instructions on how to use the score in real case LCA studies are also provided in the following tutorials.

- **Tutorial on including time-dependencies in the estimation of climate change midpoint scores of bio-based productions – Tier 1**

This document is a step-by-step procedure corresponding to the Tier 1 of ALIGNED guidance to include time-dependencies in the calculation of climate change impact scores. It is directed towards LCA practitioners with no previous experience in including temporal considerations in LCAs.

- **Tutorial on including time-dependencies in the estimation of climate change midpoint scores of bio-based productions – Tier 2 and 3**

This document is the step-by-step procedure corresponding to the Tier 2 of ALIGNED guidance to include time-dependencies in the calculation of climate change impact scores. As Tier 3 is an extension of Tier 2, instructions for Tier 3 are provided in the same document.

- **Dataset with the Biodiversity characterization factors**

This Excel spreadsheet contains the characterization factors of biodiversity impacts from GHG emissions in different **six** future scenarios and time horizon, provided by Jordan et al., (2023). It contains both, raw data from the reference and their ready-to-use formatted versions for bw2 import as a LCIA method. The data corresponding to the six combinations of (future scenarios, time horizon) are also available in six separate excel spreadsheets entitled: “*gPAF\_2050\_RCP26*”, “*gPAF\_2100\_RCP26*”, “*gPAF\_2050\_RCP45*”, “*gPAF\_2100\_RCP45*”, “*gPAF\_2050\_RCP85*”, “*gPAF\_2100\_RCP85*” to facilitate their reuse in the import tutorial (below).

- **Tutorial to import biodiversity characterization factors (.ipynb and html files)**

This python notebook tutorial contains instructions and code to import the biodiversity characterization factors (CF) from Jordan et al., (2023) as an LCIA method in a Brightway2 project to quantify **global** biodiversity impacts from 20 GHGs. The .html version allows to visualize the notebook for biodiversity characterization factors import without python.

DOI: 10.5281/zenodo.10843259

[Link to the repository](#)

## 4. Methods for handling uncertainty

### 4.1 Description of purpose

The series of documents intends to present, illustrate, and operationalize practical approaches for handling uncertainty in the LCA of bio-based products within the ALIGNED project. The primary aim is to improve decision making in the bio-based industries and sectors by allowing users to carry out uncertainty and sensitivity analysis, thereby improving and deepening the interpretation of the results of the LCAs in light of uncertainties. Additionally, the intention is to provide guidance using a tiered approach: different options are provided to perform a specific task or apply a specific method, in order of increasing accuracy but also increasing complexity.

The method includes guidelines, tutorials and code for uncertainty and sensitivity analysis in bio-based sectors, all available open access on the dedicated project repository.

### 4.2 Description of content

- **Guide on the appraisal of uncertainty in the LCA of bio-based products**

This document presents practical approaches to handle uncertainty in the environmental assessments of bio-based products within the ALIGNED project. Includes both theoretical elements, such as definitions and examples of uncertainty types and description of different approaches for uncertainty and sensitivity, as well as tiered recommendations for practitioners applying these approaches in case studies.

- **Calculator of uncertainty using pedigree matrix (.xlsx file)**

Spreadsheets to calculate uncertainty estimates using the pedigree matrix approach, with example.

- **Example of calculation of uncertainty estimates from measurement data (.xlsx file)**

Spreadsheet to calculate uncertainty estimates for the exchanges of a unit process, with example.

- **Example of calculation of sensitivity ration (.xlsx file)**

Spreadsheet showing an example of how to calculate the sensitivity ration.

- **Calculator sheet for analytical error propagation (.xlsx file)**

Spreadsheet showing an example of how to perform analytical error propagation using a simple case and a more complex case using sensitivity ratios and uncertainty estimates as starting point.

- **README instructions for running the notebooks (.txt file)**

A text file with all details needed to set up a virtual environment with the right requirements to reproduce the notebooks, including versions of databases used.

- **Data for a dummy biobased product (.xlsx and .csv files)**

Data about a fictional product system for a biobased product that is imported in the notebooks (below) and used as example for applying the various techniques of sensitivity and uncertainty analysis.

- **Tutorial for assessment of model uncertainty (.ipynb and .html files)**

Tutorial in python code using the brightway2 open source LCA software to implement a specific case of assessment of modelling uncertainty due to the modelling choice of energy mix. Can be adapted to design and perform similar types of analysis on other modelling choices.

- **Tutorial for comparative Monte Carlo simulation (.ipynb and .html files)**

Tutorial in python code using the brightway2 open source LCA software to implement the uncertainty analysis in the case of a comparative assessment of two alternative products, using stochastic simulation. Can be adapted to design and perform a similar analysis on another case.

- **Tutorial for One at Time (OAT) sensitivity analysis (.ipynb and .html files)**

Tutorial in python code using the brightway2 open source LCA software to implement a one at the time sensitivity analysis on several parameters. Can be adapted to design and perform a similar analysis on another case.

- **Tutorial for Global Sensitivity Analysis (GSA) using correlation (.ipynb and .html files)**

Tutorial in python code using the brightway2 open source LCA software to implement a global sensitivity analysis where the values of multiple parameters are changed simultaneously. Correlation analysis is used to estimate the sensitivity associated to each parameter. Can be adapted to design and perform a similar analysis on another case.

- **Tutorial for Global Sensitivity Analysis (GSA) with FAST method (.ipynb and .html files)**

Tutorial in python code using the brightway2 open source LCA software to implement a global sensitivity analysis where the values of multiple parameters are changed simultaneously. A specific sampling strategy is used and a specific sensitivity index is calculated. Can be adapted to design and perform a similar analysis on another case.

- **Importer for life cycle inventory data (.py file)**

Specific python script used to import the data

DOI: 10.5281/zenodo.10842720

[Link to the repository](#)



## 5. Methods for socio-economic assessment

### 5.1 Description of purpose

The purpose of this task is to provide scientific evidence, tools and data to support the modelling choices and assessing the sustainability of technologies and products within the bio-based sectors. Sustainability consists of three domains, economic, environmental, and social that need to be addressed. First, a techno-economic assessment (TEA) aims to assess the economic feasibility of the product or technology. Second, a model for quantification of the social indicators aims to address the social impacts of technologies or products.

Providing a TEA and a model to quantify the social indicators covers already the socio-economic assessment. In addition to that, ALIGNED extends and improves the socio-economic assessment towards a sustainability assessment by considering the environmental aspects. Hence, the third method is a stochastic multi-criteria decision analysis that aims to prioritize and rank products or technologies considering all aspects of sustainability. Indicators of all domains are taken into consideration. For the environmental dimension, the environmental indicators of task 1.3 “Methods for Life Cycle Impact Assessment” will be considered.

ALIGNED provides three open-source models: TEA, quantification of the social indicators, and a stochastic multi-criteria analysis, and accompanying tutorials for guidance and customization.

### 5.2 Description of content

The open-source models, assessing the sustainability of technologies and products within the bio-based sectors, consist of a set of tutorials and excel-based tools:

- **Model description for techno-economic assessment for technologies within the bio-based sectors**

The document consists of a brief description of the theoretical basis and a tutorial of how to use and calculate the economic indicators using the Excel-based TEA model.

- **Tool for techno-economic assessment (.xlsx file)**

The Excel-based tool contains the TEA model for calculating the economic feasibility and indicators of technologies with the aim to compare them with other alternative technologies.

- **Model description for the quantification of social indicators within the bio-based sectors**

The document consists of a brief description of the theoretical basis and a tutorial of how to use and quantify the social indicators using the Excel-based quantification model for social indicators.

- **Tool for the quantification of social indicators (.xlsx file)**

The document contains the Excel-based model for the quantification of social indicators to of technologies or products with the aim to compare them with other alternative technologies or products.

- **Model description for Stochastic multi-criteria decision analysis**

The document consists of a brief description of the theoretical basis and a tutorial for using the excel-based, stochastic multi-criteria decision analysis model and rank alternatives considering all aspects of sustainability.

- **Tool for stochastic multi-criteria decision analysis (.xlsx file)**

The document contains the excel-based stochastic multi-criteria decision analysis model to consider all sustainability indicators and rank the alternatives (e.g., technologies or products) accordingly.

DOI: 10.5281/zenodo.10843651

[Link to the repository](#)