CALIMERO

IMPROVING BIO-BASED INDUSTRIES LIFE CYCLE SUSTAINABILITY

D5.7

Guidelines and recommendations to support policies development

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LIST OF ACRONYMS

CAPEX	Capital Expenditures	**LCI**	Life Cycle Inventory
CF	Characterization Factor	**LCOP**	Levelized Cost of Production
D	Deliverable	**LCSA**	Life Cycle Sustainability Assessment
EF	Environmental Footprint	**NPV**	Net Present Value
EU	European Union	**OECD**	Organization for Economic Co-operation and Development
FTE	Full-Time Equivalent	**OELs**	Occupational Exposure Limits
FU	Functional Unit	**OHS**	Occupational Health and Safety
IOT	Input-Output Table	**PEF**	Product Environmental Footprint
IRR	Internal Rate of Return	**PP**	Payback Period
ISO	Internation Standardization Organization	**PSILCA**	Product Social Impact Life Cycle Assessment
JCP	Job Creation Potential	**SHDB**	Social Hotspot Database
LCA	Life Cycle Assessment	**WH**	Working Hours
LCC	Life Cycle Costing	**WP**	Work Package

PROJECT INFORMATION

Project full title: Industry CAse Studies AnaLysis To IMprove EnviROnmental Performance And Sustainability Of Bio-Based Industrial Processes

Acronym: CALIMERO

Call: HORIZON-CL6-2021-ZEROPOLLUTION-01

Topic: HORIZON-CL6-2021-ZEROPOLLUTION-01-06 - Increasing the environmental performance of industrial processes in bio-based sectors: construction, woodworking, textiles, pulp and paper and bio-chemicals

Start date: 1st July 2022

Duration: 48 months

List of participants:

Partner No.	PARTICIPANT ORGANIZATION | ACRONYM
1 (Coord.)	**Contactica | CTA**
2	WeLOOP | **WELOOP**
3	European Cellulose Insulation Association | **ECIA**
4	Swedish Environmental Research Institute | **IVL**
5	Neovili | **NEOVILI**
6	Cesefor | **CESEFOR**
7	Luxembourg Institute of Science and Technology | **LIST**
8	Technical University of Denmark | **DTU**
9	Techtera | **TECHTERA**
10	Essity | **ESSITY**
11	BIM Kemi AB | **BIMKEMI**
12	Ereks garment| **EREKS**

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DELIVERABLE DETAILS

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Abstract:	Within the framework of the CALIMERO project, this deliverable provides a comprehensive set of guidelines and recommendations to support policy makers in improving or designing Life Cycle Sustainability Assessment (LCSA) approaches for the bio-based economy. The report first identifies the methodological gaps currently limiting the robustness and comparability of LCSA practices across the five strategic sectors addressed in CALIMERO —construction, woodworking, textile, pulp & paper, and biochemicals. These gaps include challenges related to data availability, carbon accounting, biodiversity, toxicity, as well as social and economic dimensions. Building on these insights, the document compiles the methodological advancements developed within CALIMERO and translates them into practical guidelines and policy-oriented recommendations. By promoting harmonized sustainability assessments across bio-based sectors and integrating environmental, social, and economic considerations, this deliverable aims to support evidence-based policymaking and foster the transition towards a sustainable and circular bioeconomy.

Version	Date	Description
V1	27/10/2025	First version

1 Introduction

1.1 Supporting decision-makers in the path of configurating green policies in a bioeconomy context

For contemporary societies to function effectively, they are organized through a set of interrelated structures —from governmental institutions to regulatory frameworks— that provide the foundations for social well-being and economic activity (Fukuyama, 2014). However, despite this organizational framework, recent analyses suggest that global sustainability is increasingly under threat.

According to the most recent Global Risks Report by the World Economic Forum (2025) several factors could significantly undermine current living conditions. Short-term risks (2-year horizon) include technological challenges such as misinformation and disinformation, environmental hazards like extreme weather events and pollution, as well as geopolitical tensions and rising societal polarization. Looking ahead to the next decade, environmental concerns dominate the agenda, with biodiversity loss, ecosystem collapse, resource scarcity, and critical Earth system changes identified as key priorities. These findings underline the urgent need for systemic solutions to address growing sustainability challenges

In response to these risks, scholars and policymakers have proposed four complementary perspectives for designing climate-friendly initiatives (Aigner et al., 2023).

- Societal-oriented: Focused on redefining the human–nature relationship, this perspective advocates reducing social inequalities, dependencies on economic growth, and overexploitation of natural resources.
- System-oriented: Centered on systems of provision, it rethinks how essential goods and services —such as food, housing, and mobility— are produced and consumed.
- Market-oriented: Highlights the importance of correcting market failures and designing effective price signals and decision-making architectures to stimulate green investments.
- Innovation-oriented: Emphasizes technological and social innovation as key drivers of systemic transformation towards sustainability.

Implementing these perspectives requires translating them into concrete policy frameworks. Two main approaches can be distinguished depending on the communication channels used (Gallup, 2018). On the one hand, top-down, when the message is elaborated following a decision-making process by policy makers through policies that are communicated to the general public via media campaigns where communicators must promote a pathway to promote climate action (de Vries, 2020). On the other hand, bottom-up, when the source of the message comes from end-users, like manufacturers or consumers who, aware of the current climate crisis, demand new policies or the modification of existing ones (Luo et al., 2024).

One promising framework that integrates these perspectives is the circular bioeconomy. This concept combines the principles of the bioeconomy —focused on using biological resources to provide products, energy, and services— with a circular approach aimed at maintaining or enhancing natural capital. It emphasizes minimizing resource use, extending product lifespans, fostering reuse and recycling, and preventing waste generation, ultimately reducing energy demand and end-of-life treatment needs (Holden et al., 2023).

Several initiatives have been encouraged to promote the aforementioned approach, one of the most important being the Horizon Europe program, which incentivizes it through public funding at the continental level. This funding translates into collaboration between several countries and groups, including academia, industry, and policymakers. In the context of the CALIMERO project, a series of guidelines and

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recommendations are proposed to support policies development of five target sectors: (i) construction, (ii) woodworking, (iii) textiles, (iv) pulp and paper, and (v) biochemicals, in a bioeconomy context. In this regard, the guidelines and recommendations to be proposed by the consortium are intended to support policy makers in refining the existing life cycle sustainability evaluation methodologies.

1.2 Main aim and objectives

The primary objective of this document is to provide a series of guidelines and recommendations for policy makers when proposing improvements or novel ways of performing LCSA approaches for the particular case of the bio-economy. To that end, a series of secondary objectives have been established, including:

- Give an overview of the methodological gaps identified in terms of LCSA for each of the five-target bio-based sectors of the CALIMERO project.

- Compile the life cycle methodological improvements proposed in the CALIMERO context in the form of practical guidelines to provide recommendations to decision-makers when proposing green policies.

1.3 Report structure

Section 2 provides a summary of the LCSA gaps identified in each of the five-target bio-based sectors in CALIMERO. Section 3 gives insights about the methodological improvements proposed in the CALIMERO context, but being transformed into easy-to-apply guidelines to facilitate the implementation process, thus encouraging policy-makers to include them in further refinements of the LCSA methodology. Finally, the main conclusions obtained are collected in Section 4.

2 LCSA METHODOLOGICAL ACCOUNTING GAPS IDENTIFIED IN CALIMERO

This section summarizes the LCSA methodological gaps and limitations identified in the five sectors of CALIMERO from **D2.5** (Key levers for improvement of sustainability assessment methodology).

Although each sector presents specific methodological challenges, the analysis reveals several cross-cutting gaps that affect the bio-based systems in general. These include the limited availability and quality of Life Cycle Inventory (LCI) data, inconsistencies in carbon accounting —particularly in relation to biogenic carbon storage and temporal flows—, and the insufficient integration of circularity indicators into existing LCSA frameworks. Additionally, there is a widespread lack of standardized approaches for assessing social impacts (S-LCA) and life cycle costs (LCC), making it difficult to capture the full sustainability performance of products and systems. Finally, current methodologies inadequately address biodiversity loss and impacts on ecosystem services (ES), which are crucial dimensions for assessing the sustainability of bio-based value chains.

The following subsections provide a detailed overview of the methodological gaps identified for each of the five sectors studied in CALIMERO, complementing this cross-sectoral perspective.

- **Construction Sector**

  - Data gaps: Insufficient high-quality LCI data for bio-based materials (e.g., adhesives, paints), with datasets often missing or outdated.

  - Circularity: Limited integration of circularity indicators in the LCSA framework.

  - Carbon accounting: Temporary and permanent biogenic carbon storage is normally not recognized.

- Land use: No agreed methodology for assessing Indirect Land Use Change (iLUC), since current Product Environmental Footprint (PEF) methods only consider direct land use.

- Ecosystem services: Absence of robust indicators to effectively capture ES.

- Toxicity categories: Confusion between production-phase toxicity and use-phase impacts, so clearer separation of life cycle stages and chemical characterization is needed.

- S-LCA: Lack of consistent and standardized guidelines for evaluating social impacts in the construction sector.

- LCC: Existing LCC standards in construction stop at the inventory stage, without an impact assessment phase comparable to LCA.

- **Woodworking Sector**

  - Data gaps: Lack of high-quality and comprehensive data, leading to variable results and interpretations that make difficult the comparison across studies.

  - Circularity: Inadequate modeling of manufacturing processes. Therefore, need for process-specific models to evaluate recycling alternatives and avoid burden shifting.

  - Carbon accounting: Current methods do not take into account the atmospheric behavior of carbon storage and release, nor the cumulative heat-trapping capacity of Greenhouse Gases (GHG) emissions over time.

  - Biodiversity: Lack of indicators to assess biodiversity loss related to forestry operations.

  - Indoor health: No harmonized methodology for assessing indoor health impacts from wooden products.

  - Criticality: Limited and uncertain data for assessing raw material criticality, particularly for wood.

  - S-LCA and LCC: Absence of internationally recognized methodologies for S-LCA and LCC.

- **Textile Sector**

  - Data gaps: Lack of datasets to characterize microfiber release, insufficient coverage of production processes for many synthetic fibers, and missing LCI data on recycled fiber production.

  - Data accessibility: Need to simplify and improve data access for LCIs.

  - Land use: Existing LCIA methods fail to adequately capture location-specific land use impacts.

  - Biodiversity: Current methods inadequately address changes to biodiversity and ecosystems.

  - S-LCA: Complex supply chains and data gaps make it difficult to measure social impacts. In addition, indicators need alignment with the same Functional Unit (FU) as LCA.

  - LCC: There is no specific LCC methodology for textile manufacturing. Improvements are needed to integrate environmental costs tied to additional impact categories.

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- **Pulp & Paper Sector**
  - Data gaps: Limited datasets and Characterization Factors (CFs) for many regions.
  - Carbon accounting: Lack of clarity in assessing temporal flows and climate impacts of biogenic carbon.
  - Biodiversity: Current methods inadequately address changes to biodiversity and ecosystems.
  - Allocation: Inconsistent approaches in multi-output processes (e.g., forestry operations producing multiple products, recycling generating heat/electricity).
  - S-LCA: Methods fall short in capturing positive sectoral contributions and in addressing impacts on consumers and children.
  - LCC: Significant variability in cost data (e.g., water, energy), limiting accurate lifecycle cost forecasting.
- **Biochemical Sector**
  - Data gaps: LCA studies of certain biochemicals (e.g., bioplastics) lack detailed, clear and reproducible LCI data
  - Carbon accounting: Inconsistencies in calculating and reporting GHG emissions, especially for biogenic carbon.
  - Land use: Significant direct and indirect impacts from land use change are often omitted or inconsistently accounted for.
  - Allocation: Waste streams are often assumed to start at the point of waste creation, while virgin materials require full tracing to their original source, leading to discrepancies.
  - S-LCA: Limited frameworks for addressing value chain activities across countries and distinguishing between facility-level and individual worker impacts.
  - LCC: Lack of a standardized LCC framework. Additionally, most analyses are based on pilot-scale data, leading to inaccurate commercial-scale estimates.

3 Guidelines and recommendations to support policies development in a bioeconomy context

A number of methodological improvements have been proposed in the context of the CALIMERO project. These appear described in more detail in the WP3 deliverables. However, in order to make them more accessible and replicable for LCSA practitioners, they have been detailed in a more practical way. These methodological improvements include: biodiversity impacts, ecosystem services impacts, criticality aspects, dynamic carbon footprint, Job Creation Potential (JCP), LCC indicators, as well as novel toxicity CFs from both ProScale and UseTox.

3.1 Biodiversity impacts

3.1.1 Overview of the method

A spatially explicit method was developed to account for the spatial configuration of landscapes, a key ecological determinant of biodiversity. The approach focuses on structural landscape connectivity as a proxy for the capacity of ecosystems to support species movement and ecological processes.

Initial development targeted forestry systems, for which CFs are calculated at regional scale, making them sensitive to local variation in landscape structure and conservation value. While the method is currently applicable only to forestry, the underlying approach is designed to be extendable to other land use types.

The method is also intended to complement ongoing developments in LCA biodiversity modelling frameworks. In particular, it could improve the regional-level biodiversity assessment within the newly developed bioMAPS method (Maier, 2024), which is aligned with LANCA® and provides biodiversity CFs at global, local, and regional scales. Currently, the regional biodiversity CFs in bioMAPS are based on a Landscape Development Index that considers landscape composition but not its spatial configuration. By explicitly integrating landscape structure and connectivity, this method could offer a more ecologically relevant alternative for regional biodiversity characterization in future updates of bioMAPS.

The method models landscape connectivity using Omniscape, a circuit theory-based tool that simulates species movement based on land cover and associated resistance values. A resistance surface, a spatial raster where each cell value represents the difficulty for species to move through that part of the landscape, is first constructed to serve as input.

The connectivity impact of forestry practices is assessed by comparing the base case (with the land use of interest) to a reference scenario (in which the land use is absent). The difference in cumulative current is then normalized by the land use area, resulting in a CF expressed per m^2. For a more detailed description, see **D3.1** (Biodiversity assessment methodology definition).

For CALIMERO, CFs have been computed for a set of Swedish regions relevant to the case studies. Notwithstanding, eventual expansion to full national coverage is feasible with the current approach, although computational time needs to be considered. Extension to European scale would require data development efforts beyond the current project scope. To support broader application, the underlying scripts and brief user guide will be released publicly, enabling practitioners to generate CFs for additional regions in Sweden using the same model.

3.1.2 Methodology availability

Scripts are written in Python code and will be made available as open-source tools via the author's GitHub repository. Additionally, a brief user guide will be included to support application. The current workflow has been tested with Omniscape (version 0.6.2).

3.1.3 Practical application steps

For practitioners intending to apply the method, the workflow consists of three main steps, combining two Python scripts and the Omniscape software:

- Step 1: Run script 1, generate resistance surface. The first script generates a resistance surface for the specified region. Users define the geographic location and output path, and ensure that the required input maps (as specified in the guide) are available (automatic download links may be added in future versions). The script combines these inputs into a resistance raster.

- Step 2: Run connectivity modelling in Omniscape. The resistance surface from step 1 is imported into Omniscape, which calculates a current density map representing structural connectivity. It is noteworthy that large-scale connectivity modelling may exceed reasonable computational times without access to high-performance computing resources. For standard laptops, areas of up to 1,000-2,000 hectares are generally feasible.

- Step 3: Run script 2, calculate CFs. A second script processes the Omniscape output, comparing connectivity between the base case and a reference scenario. The difference is normalized to construct CFs per m^2.

3.2 Ecosystem services impacts

3.2.1 Overview of the method

Air pollution from $PM_{2.5}$ is a major health and environmental issue, yet its removal by forests, an important ecosystem service, is poorly captured in current LCA practice. The widely used LANCA® framework (land use indicator calculation model), recommended by the EU PEF, covers mainly soil-related services and neglects air purification.

This work introduces a novel framework for developing CFs for particulate matter ($PM_{2.5}$) removal associated with forest land use, as described in **D3.2**, using a spatially explicit and temporally dynamic modeling approach. Specifically, LANCA (Bos et al., 2020) was used to guide CF development for land use of current forest land use, while i-tree model (Hirabayashi et al., 2015) and the work of Zhang and He (2014) were used for dynamic $PM_{2.5}$ removal calculation.

The CF for PM removal loss is calculated as seen in **Equation 1**:

$$CF = -(Q_{LU,current} - Q_{ref}) \qquad (1)$$

Where:

- $Q_{lu,current}$: Annual PM removal of the current land use (in our case, specific forest types with management or degradation).
- Q_{ref}: Average annual PM removal of the reference land use (typically natural or undisturbed forest, defined by ecological zones)
- CF: Characterization Factor (kg/ha*year)

A positive CF means that the current land use quality is worse than the reference situation, while negative CF indicates better performance. As such, the CF should be labelled as particulate matter removal loss. Both $Q_{LU,current}$ and Q_{ref} are based on i-Tree model and study of Zhang and He (2014), with different vegetation-specific spatial parameters.

This methodological framework was implemented in Google Earth Engine (GEE) using an iterative function that sequentially processed each image in the $PM_{2.5}$ flux time series (2018–2022), integrating remote sensing data, meteorological conditions, and land-specific parameters. Within CALIMERO project, the method was applied to case study to calculate the CFs for $PM_{2.5}$ removal associated with forest land use in Sweden, distinguishing primary natural forest, secondary forest, intensive, and extensive use of forest, with a resolution of 10 km. CF at regional or country level is calculated through aggregation.

3.2.2 Methodology availability

The code written in GEE is available through request. This method and implementation code can be also extended to other countries of the world, due to the use of globally available datasets, such as leaf area index and canopy height. Therefore, this work provides a general framework and the possibility to calculate PM removal CFs without site-specific information for background assessment. If site-specific data is available, e.g., specific species of forest and management practices, is available, foreground assessment of CFs is also possible with LIST code implementation.

3.2.3 Practical application steps

To run the code and calculate the CFs associated with forest land use, practitioners can provide the study region- and site-specific information (species, forest management) if available, and then LIST can run the code to calculate corresponding CFs.

3.3 Criticality aspects

3.3.1 Overview of the method

A novel methodological framework is introduced to merge the criticality concept for the bio-based materials, with the goal of integrating criticality aspects into LCSA studies. This innovative approach introduces a new perspective on evaluating the raw material criticality of bio-based products by considering the potential for supply disruptions of both biotic and abiotic resources, including intermediate goods.

The assessment combines relevant indicators from the IRTC and BIRD framework into a unified methodology. Rather than focusing on isolated dimensions, the tool organizes the evaluation around a set of clearly defined risk types, providing a more holistic and actionable view of material criticality across various stages of the supply chain.

3.3.2 Methodology availability

The methodology to be followed and the calculator tool to be employed are documented in **D3.3** (Circular economy and criticality assessment methodology definition) and Annex I (Criticality Indicators). To help the implementation, an Excel-based tool was developed to assess the criticality of bio-based products. This tool can be downloaded from the CALIMERO website. Additionally, an application example for the woodworking case study of CALIMERO is provided.

3.3.3 Practical application steps

The step-by-step guide to use the criticality Excel-based tool are the following:

- Step 1: Go to the CALIMERO website: https://calimeroproject.eu/ and click on the "Knowledge centre" drop down menu and select "Documents" (see **Figure 1**). Go to the "Tools" section and download the Excel file "Annex I Criticality Indicators".

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Figure 1. "Documents" section of the CALIMERO project website.

- Step 2: Once the Excel file is downloaded, open it and take a look at the "Introduction" tab. Here you will find a brief introduction to the criticality assessment tool for bio-based materials. It also includes the instructions to follow, so be sure to read them (see **Figure 2**).

Annex I Criticality Assessment tool

Introduction

A **novel Excel-based tool** was developed to assess the criticality of bio-based products, with the goal of **integrating criticality aspects** into Life Cycle Sustainability Assessments (LCSA). This innovative approach introduces a new perspective on evaluating the raw material criticality of bio-based products by considering the potential for supply disruptions of both biotic and abiotic resources, including intermediate goods.

The assessment combines relevant indicators from the **IRTC[1] and BIRD[2] framework** into a unified methodology. Rather than focusing on isolated dimensions, the tool organizes the evaluation around a set of clearly defined risk types, providing a more holistic and actionable view of material criticality across various stages of the supply chain.

In the second tab **"Indicators and Data Source"**, compiles all indicators used in the assessment, identifying for each one the source of risk, the type of risk it contributes to, its relevance for both mineral and biotic raw materials, the original score, and the how to consider it with a normalize that score to a common range (0-100). Detailed background information on each indicator to ensure transparency and facilitate understanding for user conducting the criticality assessment.

In the **"Country performance"** tab presents all country-based indicators, along with the corresponding available data for each country. These indicators are automatically integarted into the tool's calculations and should not be modified, expect in the event of data updates.

The **"Template"** tab provides a standardized template for conducting criticality assessments. It is designed to support the development of new case studies in a structured and consistent manner. The "Results " tab display the outcomes of the criticality assessment for each intermediate flow in the illustrative case study. For each flow, the specific step in the value chain where it is consumed by the "system at risk" is identified. By linking intermediate flows to value-chain stages, the tool enables the identification of potential supply disruptions, either at the point of transaction for the intermediate flow or at any upstream stage within the value chain.

The remaining tabs relates to the specific illustrative case study used as an example. Ultimately, for any system under analysis, there will be one dedicated tab for each identified intermediate flow, so they can just be duplicated from the existing ones.

[1] Bach V, Berger M, Finogenova N, Finkbeiner M (2017b) Assessing the availability of terrestrial Biotic Materials in Product Systems (BIRD). Sustain 9:1–28. https://doi.org/10.3390/su9010137
[2] IRTC (2023) IRTC Decision Tool. https://www.irtc-decision-tool.weloop.org/. Accessed 19 Jan 2023

Figure 2. Introduction tab of the criticality assessment tool.

- Step 3: Before using the tool, it is essential to clearly define the process system you intend to analyze.

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This includes specifying the goal and scope of the assessment (as the first step when conducting LCAs), as well as identifying the specific materials and intermediate flows to be evaluated. As assessing all flows is not feasible in most cases, it is recommended to select the most relevant ones based on expert judgement or based on a pre-assessment of internal substitutability or contribution to costs (LCC). At this stage, do not omit any processes that may be relevant. In this regard, it is recommended to prepare both a system flow diagram (an example is shown in **Figure 3** for the woodworking case study addressed in CALIMERO) and a summary table, as depicted in **Table 1**, that lists all flows, corresponding value-chain steps, and the associated supplying countries. In addition, for facilitating purposes, the tool provides a set of predefined value-chain steps: availability of natural growth (for biotic resources), cultivation and harvesting (for biotic resources), refining or processing of raw materials, production of intermediate products and production of final products.

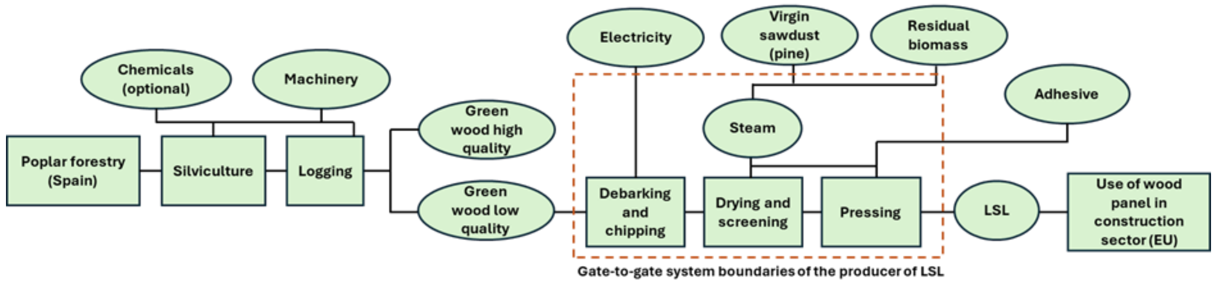

Figure 3. Schematic representation of the cradle-to-gate value chain of the production of Laminated Strand Lumber (LSL) case study addressed in CALIMERO.

Table 1. Intermediate flows consumed by the system at risk for the LSL case study addressed in CALIMERO.

Intermediate flow consumed by the system at risk	Value-chain step	Supplying countries
Low-quality green wood	Processed raw material	Spain (100%)
Electricity	Final product	NA
Virgin sawdust (pine and beech wood)	Processed raw material	Spain (100%)
Waste biomass (discarded chips, dust, trimmings, and board waste)	Processed raw material	Spain (100%)
Adhesive material (in this case a polymeric methylene diphenyl diisocyanate glue, in some other cases formaldehyde-based adhesive is used)	Final product	China (50%), Germany (25%), USA (15%), Brazil (7%), Saudi Arabia (3%)

- <u>Step 4</u>: For each intermediate flow consumed or used, it is necessary to assign it to a predefined value-chain step according to its nature of use, as illustrated in **Table 2**. This is essential, as it highlights where supply disruptions are assessed, either at that point or anywhere upstream within the value chain of the consumed or used flow. Ideally, each flow is assessed at different points in the (upstream) value chain to identify the bottleneck. In practice, value-chain steps for which data are not available may be omitted, but this needs to be acknowledged as a limitation.

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Table 2. Value-chain steps for the LSL case study addressed in CALIMERO.

Intermediate flow consumed by the system at risk	Value-chain step	Supplying countries
Low-quality green wood	Processed raw material	Spain (100%)
Electricity	Final product	NA
Virgin sawdust (pine and beech wood)	Processed raw material	Spain (100%)
Waste biomass (discarded chips, dust, trimmings, and board waste)	Processed raw material	Spain (100%)
Adhesive material (in this case a polymeric methylene diphenyl diisocyanate glue, in some other cases formaldehyde-based adhesive is used)	Final product	China (50%), Germany (25%), USA (15%), Brazil (7%), Saudi Arabia (3%)

- Step 5: For indicators (see "Indicators and data source" tab) related to supply concentration (e.g., the Herfindahl-Hirschman Index, HHI) or the performance of supplying countries (e.g., Worldwide Governance Indicators, EVI), it is important to know the countries supplying each intermediate flow and their relative production share (see **Table 3**).

Table 3. Supplying countries for the LSL case study addressed in CALIMERO.

Intermediate flow consumed by the system at risk	Value-chain step	Supplying countries
Low-quality green wood	Processed raw material	Spain (100%)
Electricity	Final product	NA
Virgin sawdust (pine and beech wood)	Processed raw material	Spain (100%)
Waste biomass (discarded chips, dust, trimmings, and board waste)	Processed raw material	Spain (100%)
Adhesive material (in this case a polymeric methylene diphenyl diisocyanate glue, in some other cases formaldehyde-based adhesive is used)	Final product	China (50%), Germany (25%), USA (15%), Brazil (7%), Saudi Arabia (3%)

- Step 6: After defining the process system under study, you can return to the Excel tool to continue the assessment. As outlined in the "Introduction" tab, the tool includes a "Template" tab that provides a standardized format for conducting criticality assessments. This template is designed to support the development of new case studies. Next, duplicate the "Template" tab for each intermediate flow identified in Step 3. Rename each duplicated tab, accordingly, following the naming convention illustrated in **Figure 4** for the LSL case study.

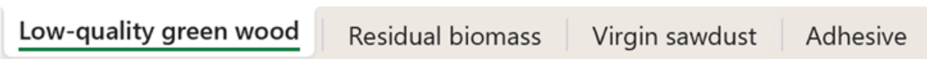

Figure 4. Individual intermediate flow tabs for the LSL case study addressed in CALIMERO.

- Step 7: Each tab appears to contain the same set of tables repeated multiple times. However, if you look closely, each one corresponds to a specific value-chain step. For each value-chain step you are able to assess, locate the corresponding table and enter the supply shares. The country-specific indicator values and a weighted average indicator score are automatically calculated by multiplying each country's share by its respective indicator value (see **Table 4** and **Table 5**).

Table 4. Screenshot of the Excel tool that provides an overview of the assessment of country-level indicators for the adhesive material used in the LSL case study addressed in CALIMERO. Country scores are weighted-average based on the supply mix to obtain a material-specific indicator score (in the first column of the figure). Note that country-level data gaps (e.g., child labour for China)

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result in a lower market representativeness for this specific indicator.

Aggregated scoring of country-level indicators	Total HHI	% of market represented		Production of final product	China	Germany	United States	Brazil	Saudi Arabia
	3408		100%	Share	50,0%	25,0%	15,0%	7,0%	3,0%
			0%	Export restrictions between 2017-2020					
54,05660412			100%	WGI - Political stability & absence of Violence/terrorism (2020)	31,13207626	7,78302	8,06604	4,7547171	2,32075
24,0961541			100%	WGI - Government effectiveness (2020)	13,70192337	2,76442	1,94711	4,44230782	1,24038
33,48076851			100%	WGI - Regulatory Quality (2020)	25	1,68269	1,875	3,76923073	1,15385
32,28365299			100%	WGI - Rule of law (2020)	23,55769157	2,16346	1,73077	3,63461536	1,19712
32,40384586			100%	WGI - Control of corruption (2020)	23,55769157	1,20192	2,59615	3,9375	1,11058
58,97584578			100%	WGI - Voice and Accountability (2020)	47,58454108	1,44928	4,05797	3,0434782	2,84058
45,46916667			100%	Fragile State Index (2022)	29,625	5,14583	4,75	4,18833333	1,76
37,4987			72%	Policy Perception Index (2021)	27,775	#VALUE!	6,0585	3,6652	#VALUE!
36,67666667			100%	Enabling trade index (2016)	20,91666667	6,29167	4,4	3,73333333	1,335
46,751			100%	Environmental Performance Index (2020)	31,35	5,7	4,605	3,416	1,68
0,378			7%	Child labour (% ages 5-17) (2010-2019)	#VALUE!	#VALUE!	#VALUE!	0,378	#VALUE!
26,11875			100%	Global Peace Index (2022)	14,575	3,0875	4,90125	2,47275	1,08225
43,2			100%	Corruption Perceptions Index CPI (2021)	27,5	5	4,95	4,34	1,41
16,468			100%	Human Development Index HDI (2019)	11,95	1,325	1,11	1,645	0,438

Table 5. Screenshot of the Excel tool that provides an overview of the assessment of country-level indicators for the virgin sawdust used in the LSL case study addressed in CALIMERO. Country scores are weighted-average based on the supply mix to obtain a material-specific indicator score (in the first column of the figure). Note that country-level data gaps (e.g., child labour for Spain) result in a lower market representativeness for this specific indicator

Aggregated scoring of country-level indicators	Total HHI	% of market represented		Refining countries / Processing	Spain
	10000		100%	Share	100.0%
			0%	Export restrictions between 2017-2020	
41.98113251			100%	WGI - Political stability & absence of Violence/terrorism (2	41.98113251
22.11538696			100%	WGI - Government effectiveness (2020)	22.11538696
26.44230652			100%	WGI - Regulatory Quality (2020)	26.44230652
21.63461304			100%	WGI - Rule of law (2020)	21.63461304
23.55769348			100%	WGI - Control of corruption (2020)	23.55769348
19.32366943			100%	WGI - Voice and Accountability (2020)	19.32366943
33.91666667			100%	Fragile State Index (2022)	33.91666667
41.12			100%	Policy Perception Index (2021)	41.12
28.66666667			100%	Enabling trade index (2016)	28.66666667
36			100%	Environmental Performance Index (2024)	36
0			0%	Child labour (% ages 5-17) (2010-2019)	#VALUE!
17.8			100%	Global Peace Index (2022)	17.8
39			100%	Corruption Perceptions Index CPI (2021)	39
9.6			100%	Human Development Index HDI (2019)	9.6

- Step 8: In addition to country-specific indicators, some indicators are material specific (i.e., not linked to supplying countries) and may be assessed at multiple points in the value chain. For these indicators, the bottleneck value is determined by selecting the value-chain step with the highest score. The orange boxes of **Table 6** indicate for which value-chain step data may be inserted. The bottleneck value is then automatically calculated in the final column. The calculation is available at the bottom of each flow-specific tab in the Excel tool. The example shown below is taken from the adhesive material tab used in the LSL example case-study.

Table 6. Calculating the bottleneck value based on indicator scoring at multiple steps in the value chain using the Excel tool. Illustration for the adhesive material used in the LSL case study addressed in CALIMERO.

	Raw material extracted from nature	Raw material extracted from cultivation (harvesting) / Mining	Processed raw material	Intermediate product	Final product	Bottleneck value
Amount of phosphorous applied (kg) in a product system						0
Amount of land used (h/year) in a product system						0
Cradle-to-gate LCA (single score)						0
Climate change						0
Acidification						0
Eutrophication						0
Ozone Depletion						0
Photochemical ozone formation						0
Cumulative energy demand						0
Threatened Species Index (TSI)						0
Primary material use (%)					100%	100%
Extraction rate						
Resource stocks						
Replenishment rate (biotic resources)						
Biotic resource depletion						#DIV/0!
Growth rate						
Yield						
Replenishment rate (man-made biotic materials)						0
Substance of very high concern for Authorisation (REACH framework)					Yes	100
% supply as by-product						0%
Compound Annual Growth Rate between 2020-2030					5,2%	5,20%
Compound Annual Growth Rate between 2018-2040						0,00%
Compound Annual Growth Rate between 2020-2050						0,00%
Production/consumption increase/decrease over the last five years						0,00%
% expected demand growth						5,20%

Note that for the adhesive material, the substance is classified as a Substance of Very High Concern (SVHC) under the REACH regulation. It is currently included in the Community Rolling Action Plan (CoRAP), meaning that certain EU countries are scheduled to assess the substance for potential future restrictions. In addition, some uses of the substance are already restricted. In the tool, assigning a value of “Yes” to this indicator results in an automatic maximum score of 100, reflecting a high regulatory concern. Additionally, data for demand growth is also included based on available projections (e.g. across different time horizons), the tool calculates the bottleneck value by selecting the highest score among the assessed time periods. This approach highlights the most critical growth scenario for the material.

- Step 8: At this stage, you should have completed the indicator results for each intermediate flow in their respective flow tabs. To analyze and compare the results, go to the “Results” tab. Create a new column for each flow, and rename the column, such that the name corresponds exactly to the material spreadsheet. The indicator scores are then automatically extracted into the corresponding columns. In the illustrative case study, the indicator scores of the intermediate flows are compared with one another, and also with the scores for cobalt and lithium, calculated using the IRTC tool (shown in **Table 7**). Cobalt and lithium are used as reference materials because both are classified as “critical” and “strategic” by the European Commission (European Parliament; Council of the European Union, 2024), though they represent different supply risk profiles. Lithium and cobalt provide context on what scoring could be considered “high” for each indicator. If your criticality assessment evaluates a large number of flows, adding such “benchmark” materials is not necessary, as the flows of the system at hand may be compared with one another.

Table 7. Impression of the overview of indicator scoring for the intermediate flows of the illustrative example LSL case study addressed in CALIMERO), as well as for cobalt and lithium

Indicator	Low-quality green wood	Virgin sawdust	Residual biomass	Adhesive	Cobalt	Lithium	Max
Supply is dominated in a few countries (bottleneck)	100,0	100,0	100,0	81,2	88,0	83,7	100,0
WGI - Political stability & absence of Violence/terrorism (2020)	42,0	42,0	42,0	54,1	78,3	56,0	78,3
WGI - Government effectiveness (2020)	22,1	22,1	22,1	24,1	77,2	26,3	77,2
WGI - Regulatory Quality (2020)	26,4	26,4	26,4	33,5	77,7	35,7	77,7
WGI - Rule of law (2020)	21,6	21,6	21,6	32,3	80,1	33,1	80,1
WGI - Control of corruption (2020)	23,6	23,6	23,6	32,4	79,8	31,7	79,8
WGI - Voice and Accountability (2020)	19,3	19,3	19,3	59,0	72,5	50,2	72,5
Fragile State Index (2022)	33,9	33,9	33,9	45,5	76,2	43,5	76,2
Policy Perception Index (2021)	41,1	41,1	41,1	37,5	48,4	34,8	48,4
Enabling trade index (2016)	28,7	28,7	28,7	36,7	54,6	36,5	54,6
Environmental Performance Index (2024)	36,0	36,0	36,0	50,1	56,2	51,5	56,2
Child labour (% ages 5-17) (2010-2019)	0,0	0,0	0,0	0,4	10,9	2,7	10,9
Global Peace Index (2022)	17,8	17,8	17,8	26,1	45,8	25,0	45,8
Corruption Perceptions Index CPI (2021)	39,0	39,0	39,0	43,2	69,6	44,9	69,6
Human Development Index HDI (2019)	9,6	9,6	9,6	16,5	41,7	18,1	41,7
…	…	…	…	…	…	…	…

Since not all indicators are originally assessed on a 0-100 scale, the scores are normalized relative to the flow with the highest value (as shown in the "Max" column of **Table 7**). After normalization, you can plot the scores in a graph (see **Figure 5**), which helps to visually identify criticality hotspots across different flows. An example of how to interpret these plotted results for the LSL case-study is provided in **D3.3**.

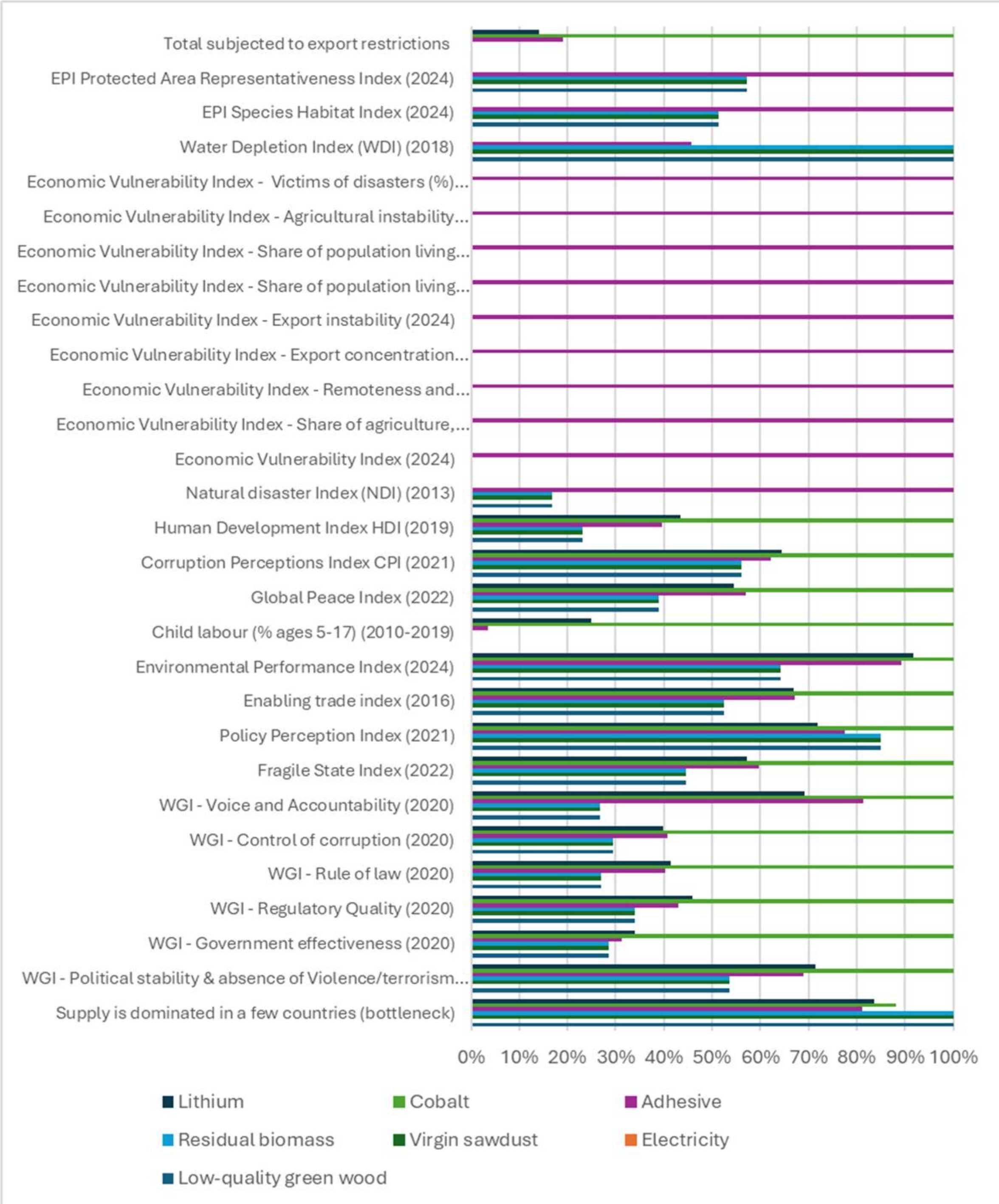

Figure 5. Comparative assessment of criticality indicators of the intermediate flows related to the Laminated Strand Lumber (LSL) case study addressed in CALIMERO, as well as cobalt and lithium.

3.4 Dynamic carbon footprint

3.4.1 Overview of the method

The Dynamic carbon footprint approach is designed for bio-based systems to assess GHG emissions over time, allowing the evaluation of potential climate benefits compared to fossil-based alternatives. It is based on the Dynamic Process-based Life Cycle Assessment (DyPLCA) framework (Pigné et al., 2020) and enables the modelling of the LCI, including GHG emissions throughout the entire life cycle and the associated background system.

DyPLCA comprises three components: a modelling framework, a model/tool, and a database. While the modelling framework and its temporal parameters, such as process duration and emission profiles, have remained unchanged, the model and database have been updated. The model has been adapted with the introduction of a new module, bwdyplca, which exports LCI data from Brightway to DyPLCA, along with a Typescript connector to read input files. Most importantly, the DyPLCA database has been upgraded from version 1.0, containing temporal parameter data for 15,985 processes in ecoinvent 3.2, to version 2.0, covering 24,641 processes in ecoinvent 3.10.

A more detailed description of the methodology appears is documented in **D3.4** (Carbon footprint assessment methodology including temporal dimension definition).

3.4.2 Methodology availability

The original DyPLCA tool (http://dyplca.list.lu) is currently not anymore operational on the web for public use; so far, only local testing and development has been done. Additionally, enhancements to the graphical user interface are ongoing. When these issues are closed, users will be able to upload their LCIs to the tool to obtain results through this alternative pathway where steps can be executed independently from LIST.

3.4.3 Practical application steps

A following procedure has been outlined to obtain a dynamic carbon footprint (based on Ecoinvent background processes), readily applicable to CALIMERO case studies or any other:

- Step 1: Create the LCI of your case in a Brightway-compatible format comprising foreground processes with background connections to Ecoinvent processes (preferably version 3.11, but if earlier version then an extra matching may be needed).
- Step 2: The LCIs are uploaded to the locally running version of DyPLCA using bwdyplca. Implicitly during this step, there is an automatic linking between the DyPLCA v2 database (ei3.10 processes) and the background ecoinvent processes of the LCI. If a version earlier than 3.10 for ecoinvent is used, a manual check should be performed if this is done.
- Step 3: Temporal parameter data, collected a priori, needs to be added for the new foreground processes. This is done by LIST.
- Step 4: The DyPLCA model is run.
- Step 5: The dynamic inventory outputs can then be obtained either via a Python script or Excel.
- Step 6: Dynamic climate change impact assessment approaches can then be imposed on these inventories. Prominently, the freely available Climate Change Impact (CCI) tool (https://www.insa-toulouse.fr/cci-tool/) of INSA can be used. The CCI-tool calculates climate change indicators as a function of time: radiative forcing, cumulative radiative forcing, global mean temperature change, cumulative global mean temperature change. Moreover, this tool has been tailored to read output files of DyPLCA, making it directly implementable. For the integrated score GWP100 from product usage start until 100 years after it is considered, aligning considerably with RE2020 (with dynamic span of usage).
- Step 7: Interpretation of the overall results.

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3.5 Job Creation Potential

3.5.1 Overview of the method

The JCP is a social indicator from an S-LCA that quantifies the total number of jobs that a product system can create. To do this, the LCI (the same from an LCA study for example) is transformed into job units accounted for both those positions created in the background system and the foreground system. A more detailed description of the methodology is documented in **D3.5** (Definition of relevant socio-economic indicators to include in LCSA of target bio-based industries).

3.5.2 Methodology availability

To facilitate its application an Excel calculator tool was developed, which is publicly available as Annex A (Job Creation Potential calculator tool) in **D3.5**, and also can be found in the CALIMERO website.

3.5.3 Practical application steps

A description of the steps needed to follow for using the tool is provided:

- Step 1. Go to the CALIMERO website: https://calimeroproject.eu/ and click on the "Knowledge centre" drop down menu and select "Documents" (see **Figure 6**). Go to the "Tools" section and download the Excel file "Annex A. Job Creation Potential calculator tool".

Figure 6. "Documents" section of the CALIMERO project website.

- Step 2. Once the Excel file is downloaded, open it and take a look at the Introduction tab. Here you will find a brief introduction to the S-LCA methodology and the JCP. It also describes the instructions to follow, so be sure to read them (see **Figure 7**).

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Annex A. Job Creation Potential calculator tool

Introduction

Job Creation Potential (JCP) is a social indicator from an S-LCA (Social Life Cycle Assessment) that quantifies the total number of jobs that a product system can create. In this sense, it represents the aggregation of jobs created internally (foreground system) and those generated by suppliers to support the process (background system). Likewise, this methodology has the advantage of relying on the same inventory information used in Life Cycle Assessment (LCA), leading to significant time and resource savings.

On the one hand, foreground jobs are determined by quantifying the Working Hours (WH) associated. The required WH are then divided by the Full-Time Equivalent (FTE) at the country level, which represents the number of hours a full-time employee works for an organization over a specific time period (e.g., one year).

On the other hand, the methodology developed by Pillain et al. (2019)[1] is used as a reference to quantify background jobs. This involves transforming the Life Cycle Inventory (LCI) into WH and incorporating FTE factors. Similarly, a distinction is made between direct induced jobs (those created directly by suppliers to service the process) and indirect induced jobs, which are created at a supplier's supplier to develop a direct input.

The total JCP is then calculated as the sum of both: jobs from the foreground and background systems. Likewise, as an innovative contribution, the JCP is calculated per Functional Unit (FU) and can be further scaled using a Scaling Factor (SF) if desired.

A detailed step-by-step description of the procedure is provided in the **Methodology** section. Additionally, guidance on how to use the JCP tool is shown in the **Instructions** section. Finally, an index of the different sheets included in this Excel file is available, along with a contact email for further assistance (see **Contact** section).

[1]Pillain, B., Viana, L.R., Lefeuvre, A., Jacquemin, L., Sonnemann, G., 2019. Social life cycle assessment framework for evaluation of potential job creation with an application in the French carbon fiber aeronautical recycling sector. Int. J. Life Cycle Assess. 24, 1729–1742. https://doi.org/10.1007/s11367-019-01593-y

Figure 7. "Introduction" tab of the Job Creation Potential calculator tool.

- Step 3. This tool calculates both foreground and background jobs. For the foreground, first, the total number of Working Hours (WH) must be entered in the "Working Hours (WH)" sheet. Then, in the "Job Creation Potential (JCP)" sheet, select the country of the study, and the Full-Time Equivalent (FTE) will be automatically filled in. This way, the JCP (foreground) per FU is obtained, as shown in **Figure 8**.

Job Creation Potential (JCP) per FU - foreground system

Foreground jobs are those created by the product system itself.

$$JCP\ (foreground) = \frac{WH_{foreground}}{FTE}$$

Step 1 - Working hours (WH) accounting

Variable	Description	Value	Unit	Source
$WH_{foreground}$	Total number of hours worked in the foreground system per Functional Unit (FU)	41,753.60	$h \cdot FU^{-1}$	Primary data (see Working Hours (WH))

Step 2 - Full-Time Equivalent (FTE) estimation

Variable	Description	Country	Value	Unit	Source
FTE	Number of hours a full-time employee works for an organization over a specific time period (e.g., one year)	Spain	1,697.60	$h \cdot (worker \cdot year)^{-1}$	Full-Time Equivalent (FTE)

Step 3 - Calculation of foreground jobs

Variable	Description	Value	Unit
JCP (foreground)	Jobs created in the foreground system	24	$(worker \cdot year) \cdot FU^{-1}$

Figure 8. Steps to be followed for the calculation of the foreground jobs.

- Step 4. For the background jobs, if the Input-Output Tables (IOTs) approach is followed, in the 'Job coefficients (f)' sheet, update the f values for each economic sector involved (see "Appendix A. Job coefficients (f) estimation" in **D3.5**). Then, in the "Job Creation Potential (JCP)" sheet, select the corresponding economic sector for each input/output, and f values will be automatically filled in (see **Figure 9**).

Step 1 - Jobs coefficients (f) selection

Jobs coefficients can be obtained from Input-Output Tables (IOTs) or from social databases (e.g., SHDB, PSILCA or EXIOBASE). The IOTs option is developed in *Appendix A. Job coefficients (f) estimation*. An examples is provided for the Spanish context in 2018.

Description	Unit	Source
Job coefficient	$h \cdot €^{-1}$	OECD (see Job coefficients (f))

Input/output	Economic sector	f ($h \cdot €^{-1}$)
Process 1	Agriculture, hunting, forestry	0.457
Process 2	Wood and products of wood and cork	0.166
Process 3	Coke and refined petroleum products	0.003
Process 4	Electricity, gas, steam and air conditioning supply	0.004
Process 5	Water supply; sewerage, waste management and remediation activities	0.009

Figure 9. Job coefficients (f) selection using the input-output tables option.

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- <u>Step 5</u>. Fill out the "Life Cycle Inventory (LCI)" sheet with all inputs/outputs with an associated cost and relativize them based on the selected FU (see **Figure 10**). In the "Job Creation Potential (JCP)" sheet, enter the costs of each input, and the value of Y (economic flow) will be automatically generated.

Life Cycle Inventory (LCI)

Inventory of the inputs/outputs.

Step 1 - Collection of the inputs/outputs of the product system which have an associated cost

Input/output	Value	Unit
Process 1	25,000.00	kg
Process 2	7,500.00	kg
Process 3	92,500.00	kWh
Process 4	11,100.00	kWh
Process 5	2,000.00	L

Step 2 - Relativization of the inventory by the FU

Input/output	Value	Unit
Process 1	5,000.00	$kg{\cdot}FU^{-1}$
Process 2	1,500.00	$kg{\cdot}FU^{-1}$
Process 3	18,500.00	$kWh{\cdot}FU^{-1}$
Process 4	2,220.00	$kWh{\cdot}FU^{-1}$
Process 5	400.00	$L{\cdot}FU^{-1}$

Figure 10. Compilation of the life cycle inventory data and relativization by the functional unit selected.

- <u>Step 6</u>. The WH related to the background system are automatically calculated by multiplying the job coefficients (f) by the economic flow (Y), if the IOT approach is used. Conversely, if a social database is used, you can directly enter the WH in the "Job Creation Potential (JCP)" sheet, as shown in **Figure 11**.

Step 2 - Working Hours (WH) accounting

Accounting of the WH for each input/output according to the associated economic sector.

Description	Unit	Source
Hours worked necessary to produce a particular input/output of the inventory	$h{\cdot}FU^{-1}$	Own calculation

Input/output	Economic sector	$WH_{background}$ ($h{\cdot}FU^{-1}$) Using IOTs	Using social databases
Process 1	Agriculture, hunting, forestry	5,713.36	
Process 2	Wood and products of wood and cork	248.93	
Process 3	Coke and refined petroleum products	323.20	
Process 4	Electricity, gas, steam and air conditioning supply	20.58	
Process 5	Water supply; sewerage, waste management and remediation activities	35.43	

Figure 11. Working hours accounting associated per each economic sector.

- <u>Step 7</u>. JCP relative to the background system is determined by choosing the country of origin of each input to obtain the specific FTE. The results can be distinguished between direct and indirect job positions if the "Direct-Indirect Job" sheet is completed with the relevant data for a country and reference year (see **Figure 12**).

Step 3 - Calculation of background jobs

The JCP of the background system is calculated by means of dividing the WH (of the background system) by the FTE. The background jobs are those generated by suppliers to support the project.

$$JCP\ (background) = \frac{WH_{background}}{FTE}$$

Input/output	Economic sector	FTE ($h{\cdot}(worker{\cdot}year)^{-1}$) Country	Value	JCP (background) unrounded $(worker{\cdot}year){\cdot}FU^{-1}$	JCP (background) rounded $(worker{\cdot}year){\cdot}FU^{-1}$	JCP (background) direct jobs $(worker{\cdot}year){\cdot}FU^{-1}$	JCP (background) indirect jobs $(worker{\cdot}year){\cdot}FU^{-1}$
Process 1	Agriculture, hunting, forestry	Spain	1,697.60	3.37	3.00	2.00	1.00
Process 2	Wood and products of wood and cork	Portugal	1,738.00	0.14	-	-	-
Process 3	Coke and refined petroleum products	Germany	1,380.70	0.23	-	-	-
Process 4	Electricity, gas, steam and air conditioning supply	Unknown	1,826.00	0.01	-	-	-
Process 5	Water supply; sewerage, waste management and remediation activities	Spain	1,697.60	0.02	-	-	-
Total				3.77	3.00	2.00	1.00

Figure 12. Calculation of background jobs, differentiated by direct and indirect.

- <u>Step 8</u>. Introduce on the "Job Creation Potential (JCP)" sheet a specific Scaling Factor (SF). An example is provided based on the potential availability of the main Raw Material (RM) used in a specific context (in terms of time and location). In this way, the FU according to the SF selected is automatically obtained, as seen in **Figure 13**.

Step 5 - Scaling Factor (SF) identification

A Scaling Factor (SF) is used to estimate the potential creation of jobs in a hypothetical case. The SF is determined by dividing the potential availability of Raw Material (RM) within a specific context —both in terms of time and location (e.g., the RM available over the course of one year in Spain)— by the amount required to produce the FU.

Variable	Description	Unit	Unit
RM potential	Availability of the main RM in a specific context (e.g., Spain in 2018)	200,000	kg_{RM}
RM process	RM used to comply with the FU	5,000	kg_{RM} FU^{-1}
SF	Scaling Factor	40	FU (SF)

Figure 13. Example of estimation of the scaling factor for a temporal and geographical context.

- <u>Step 9</u>. The total JCP upscaled, including both the jobs obtained from foreground and background systems will be automatically calculated (see **Figure 14**).

Item		Value
JCP (upscaled - foreground) (worker·year)		960
JCP (upscaled - background) (worker·year)	Total	148
	Direct	*114*
	Indirect	*34*
JCP (upscaled) (worker·year)		1,108

Figure 14. Upscale process for both the foreground and background jobs created.

As previously mentioned, if the IOTs are used, an Excel file is available to facilitate the calculation of job coefficients. This file, titled "Appendix A. Job Coefficients (f) estimation", can be downloaded from the CALIMERO website. It follows the same structure as the JCP tool, but the procedure for obtaining the results will be detailed below.

- <u>Step i</u>. Go to the CALIMERO website: https://calimeroproject.eu/ and click on the "Knowledge centre" drop down menu and select "Documents" (see **Figure 15**). Go to the "Tools" section and download the Excel file "Appendix A. Job Coefficients (f) estimation".

Figure 15. "Documents" section of the CALIMERO project website.

- <u>Step ii</u>. Once the Excel file is downloaded, the introduction sheet provides a brief description of the methodology along with step-by-step instructions for obtaining the job coefficients (see **Figure 16**).

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Methodology

i. Calculation of the direct coefficients of the volume of WHs

The initial step involves constructing a matrix (S_j) that incorporates the direct WHs (Working Hours) associated with the economic sector identified in the Input-Output Tables - IOTs (K_j) and the monetary production of this economic sector (X_j) (**Equation 1**). If information on direct WHs is not available, it can be estimated from the Workers Per Sector (WPS) and the annual hours worked per employee, denoted as Full-Time Equivalent (FTE) (**Equation 2**).

$$S_j = \frac{K_j}{X_j} \quad \textbf{Equation 1}$$

$$K_j = WPS \cdot \mathrm{FTE} \quad \textbf{Equation 2}$$

Where:
S_j: Hours worked per monetary unit in an economic sector j (h·€$^{-1}$)
K_j: Amount of direct WHs within an economic sector j (h)
X_j: Total quantity of monetary output per economic sector j, i.e., IOT (€)
WPS: Number of workers per sector (worker)
FTE: Total number of hours worked per year by one employee (h·(worker·year)$^{-1}$)

ii. Calculation of the total induced WHs (direct and indirect)

The directly and indirectly induced WHs associated with each economic sector in the IOTs is then calculated by applying the inverse matrix of Leontief (**Equation 3**). Note that $(I-A)^{-1}$ represents the inverse matrix of Leontief.

$$f = S \cdot (\mathrm{I} - \mathrm{A})^{-1} \quad \textbf{Equation 3}$$

Where:
f: Direct and indirect WHs required to produce one monetary unit relative to a specific economic sector (h·€$^{-1}$)
S: Matrix of hours worked per monetary unit in an economic sector (h·€$^{-1}$)
I: Identity matrix
A: Matrix of technical coefficients

Figure 16. "Methodology" tab of the Job coefficients estimation tool.

- <u>Step iii</u>. The file is pre-filled using Spain and the year 2018 as a reference, as it is the most recent year available in the OECD's IOTs. If the selected country or year does not align with the needs of the user, the first step is to complete the "Full-Time Equivalent (FTE)" sheet with FTE data for the desired reference year and country, as shown in **Figure 17**.

Full-Time Equivalent (FTE)

Total number of hours worked per year by one employee.

Country	FTE (h·(worker·year)$^{-1}$)
Unknown	1,843
Afghanistan	1,830
Albania	1,927
Algeria	2,019
Angola	1,913
Argentina	1,709
Armenia	1,853
Aruba	1,820
Australia	1,654
Austria	1,502
Azerbaijan	1,589
Bangladesh	2,167
Belarus	1,806
Belgium	1,580
Belize	1,802
Benin	1,866
Bermuda	1,931
Bhutan	2,513
Bolivia	1,756
Bosnia and Herzegovina	1,913
Botswana	2,024

Data from the OECD[1] (Organization for Economic Co-operation and Development) is used to estimate the Full-Time Equivalent (FTE) relative to each country. However, there are data gaps for some countries, so estimations based on ILOSTAT[2] (International Labor Statistics) were made for non-OECD countries. In this regard, ILOSTAT provides average weekly hours per employee, which have been relativized per year considering the worldwide average number of working weeks in a year. The reference year is 2018.

[1] *https://stats.oecd.org/viewhtml.aspx?datasetcode=ANHRS&lang=en*
[2] *https://ilostat.ilo.org/topics/working-time/*

Figure 17. Full-Time Equivalent for the year 2018.

- <u>Step iv</u>. Complete the number of workers per sector in the "Workers Per Sector (WPS)" sheet (see **Figure 18**).

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Workers per sector (WPS)

Total number of employees within a specific economic sector.

Economic sector	WPS (persons, thousands)
Agriculture, hunting, forestry	483.3
Fishing and aquaculture	24.5
Mining and quarrying, energy producing products	19.6
Mining and quarrying, non-energy producing products	
Mining support service activities	
Food products, beverages and tobacco	391.8
Textiles, textile products, leather and footwear	115.9
Wood and products of wood and cork	47.2
Paper products and printing	45.2
Coke and refined petroleum products	9.0
Chemical and chemical products	92.5
Pharmaceuticals, medicinal chemical and botanical products	41.0
Rubber and plastics products	98.4
Other non-metallic mineral products	91.4
Basic metals	61.8
Fabricated metal products	232.2

The number of workers is obtained from the OECD[1], using Spain and the year 2018 as a reference.
[1] OECD - Employment by activities and status (ALFS)

Figure 18. Example of workers per sector for Spain in year 2018.

- Step v. Enter the IOT and the inverse matrix of Leontief in the "IOT (Xj)" and "IOT inverse Leontief" sheets, respectively. **Figure 19** provides an example of the IOT for Spain in 2018. This matrix is directly obtained from the OECD and simply needs to be copied and pasted into the corresponding sheet.

Input-Output Tables (IOTs) 2021 ed.

IOTs describe the sales and purchase relationships between producers and consumers within an economic sector (j). It is expressed as variable X_j.

Total IOTs data for Spain for the year 2018 (the most recent available) was selected from the OECD[1]. The unit of the data is in millions of USD.
[1] OECD - Input-Output Tables (IOTs) 2021 ed

Economic sector	Agriculture, hunting, forestry	Fishing and aquaculture	Mining and quarrying, energy producing	Mining and quarrying, non-energy producing	Mining support service activities	Food products, beverages and tobacco	Textiles, textile products, leather and footwear	Wood and products of wood and cork	Paper products and printing	Coke and refined petroleum products	Chemical and chemical products
Agriculture, hunting, forestry	2.92E+03	2.19E+01	3.00E-01	5.20E+00	2.00E-01	3.42E+04	8.11E+02	2.31E+02	5.43E+02	2.74E+01	1.40E+03
Fishing and aquaculture	9.50E+00	3.00E+01	0.00E+00	0.00E+00	0.00E+00	2.04E+02	3.00E-01	0.00E+00	1.00E-01	2.00E-01	1.10E+00
Mining and quarrying, energy producing products	5.30E+00	1.20E+00	5.00E-01	1.15E+01	6.20E+00	7.30E+00	8.00E-01	9.00E-01	1.60E+00	2.97E+04	2.19E+02
Mining and quarrying, non-energy producing products	6.70E+00	4.40E+00	3.00E-01	8.42E+01	3.80E+00	1.00E+02	4.20E+00	2.00E+00	7.88E+01	2.90E+00	3.09E+02
Mining support service activities	1.50E+00	2.00E-01	2.70E+00	3.12E+01	8.20E+00	2.30E+00	1.00E-01	0.00E+00	2.80E+00	5.39E+01	4.20E+00
Food products, beverages and tobacco	9.50E+03	2.10E+02	3.80E+00	4.39E+01	1.20E+00	2.51E+04	2.14E+02	2.72E+01	1.47E+02	1.17E+02	7.51E+02
Textiles, textile products, leather and footwear	2.66E+01	3.95E+01	4.00E-01	2.30E+00	5.00E-01	1.28E+02	3.46E+03	9.80E+00	1.26E+02	8.50E+00	2.05E+02
Wood and products of wood and cork	4.36E+01	1.30E+01	8.00E-01	2.84E+01	7.00E-01	3.39E+02	2.24E+01	2.12E+03	1.40E+02	6.80E+00	6.63E+01
Paper products and printing	3.08E+01	1.20E+00	4.00E-01	8.60E+00	5.00E-01	2.82E+03	2.55E+02	2.63E+02	5.81E+03	1.92E+01	7.01E+02
Coke and refined petroleum products	6.31E+02	1.75E+02	9.10E+00	1.75E+02	1.11E+01	3.02E+02	5.32E+01	1.36E+02	1.42E+02	1.73E+03	1.33E+03
Chemical and chemical products	1.99E+03	2.38E+01	3.50E+00	1.52E+02	6.70E+00	1.17E+03	4.96E+02	3.38E+02	7.55E+02	3.59E+02	1.07E+04
Pharmaceuticals, medicinal chemical and botanical products	1.87E+02	3.80E+00	5.00E-01	6.10E+00	3.00E-01	2.53E+02	2.75E+01	1.56E+01	8.90E+01	2.36E+01	3.02E+02
Rubber and plastics products	3.28E+02	1.40E+01	1.70E+00	2.06E+01	1.30E+00	1.84E+03	2.65E+02	1.61E+02	3.65E+02	2.47E+01	1.22E+03
Other non-metallic mineral products	5.59E+01	3.30E+00	4.10E+00	2.25E+02	2.10E+00	1.13E+03	5.34E+01	7.20E+01	6.09E+01	3.05E+01	6.70E+02
Basic metals	6.71E+01	3.60E+00	2.60E+00	1.86E+01	4.20E+00	1.88E+02	2.73E+01	1.72E+01	1.72E+02	4.56E+01	1.44E+02
Fabricated metal products	6.07E+02	1.54E+01	4.70E+00	4.56E+01	7.10E+00	8.84E+02	1.53E+02	7.34E+01	8.41E+01	2.48E+02	5.04E+02
Computer, electronic and optical equipment	1.50E+01	7.70E+00	3.00E-01	5.20E+00	1.20E+00	4.29E+01	9.20E+00	5.20E+00	5.00E+01	1.65E+01	3.08E+01
Electrical equipment	5.06E+01	1.16E+01	8.00E-01	1.46E+01	1.90E+00	1.19E+02	1.85E+01	1.32E+01	2.90E+01	4.43E+01	5.81E+01
Machinery and equipment, nec	1.53E+02	2.70E+01	5.30E+00	1.08E+02	1.27E+01	2.85E+02	3.53E+01	7.01E+01	2.01E+02	1.33E+03	1.68E+02
Motor vehicles, trailers and semi-trailers	8.74E+01	1.47E+01	1.30E+00	1.26E+01	1.90E+00	1.96E+02	2.79E+01	2.56E+01	4.21E+01	7.16E+01	8.49E+01
Other transport equipment	3.37E+01	2.24E+01	9.00E-01	1.23E+01	1.10E+00	7.16E+01	8.30E+00	1.35E+01	2.77E+01	2.55E+01	4.53E+01
Manufacturing nec; repair and installation of machinery and equipment	2.09E+02	8.87E+01	5.40E+00	7.04E+01	7.40E+00	4.92E+02	1.25E+02	1.57E+02	1.92E+02	1.23E+02	2.55E+02

Figure 19. Example of IOT for Sapin and year 2018.

- Step vi. Although no data needs to be entered, ensure that the calculations on the 'Working Hours (Kj)' and 'Sj' sheets are performed correctly (see **Figure 20**).

Direct working hours

Amount of direct hours worked in a specific sector (j). It is expresed as the variable K_j.

Economic sector	K_j (h)
Agriculture, hunting, forestry	820
Fishing and aquaculture	42
Mining and quarrying, energy producing products	33
Mining and quarrying, non-energy producing products	0
Mining support service activities	0
Food products, beverages and tobacco	665
Textiles, textile products, leather and footwear	197
Wood and products of wood and cork	80
Paper products and printing	77
Coke and refined petroleum products	15
Chemical and chemical products	157
Pharmaceuticals, medicinal chemical and botanical products	70
Rubber and plastics products	167
Other non-metallic mineral products	155
Basic metals	105
Fabricated metal products	394
Computer, electronic and optical equipment	42
Electrical equipment	119
Machinery and equipment, nec	185
Motor vehicles, trailers and semi-trailers	271
Other transport equipment	82
Manufacturing nec; repair and installation of machinery and equipment	183
Electricity, gas, steam and air conditioning supply	65
Water supply; sewerage, waste management and remediation activities	321
Construction	1713
Wholesale and retail trade; repair of motor vehicles	426
Land transport and transport via pipelines	662

The direct WHs associated with an economic sector are calculated using the following formula:

$$K_j = FTE \cdot (WPS \cdot 1000^{-1})$$

Where:
Kj: Amount of direct WHs within an economic sector j (h)
FTE: Total number of hours worked per year by one employee at country level (h·(worker·year)$^{-1}$)
WPS: Number of workers per sector (worker)

Therefore, the unit of measure is million of hours.

Figure 20. "Working hours (Kj)" sheet of the Job coefficients estimation tool.

- Step vii. The results of job coefficients (f) in terms of hours per United States Dollars (USD) are presented in the 'f (calculation)' sheet. To convert this to €, fill in the exchange rate in cell G16. Finally, the results of f in hours per € are presented in column D, as can be seen in **Figure 21**.

Job coefficients (f)

Direct and indirect Working Hours (WHs) required to produce one monetary unit.

Economic sector	f (h·USD^{-1})	f (h·€$^{-1}$)
Agriculture, hunting, forestry	3.88E-01	4.57E-01
Fishing and aquaculture	2.46E-01	2.90E-01
Mining and quarrying, energy producing products	3.64E-02	4.29E-02
Mining and quarrying, non-energy producing products	6.38E-02	7.52E-02
Mining support service activities	6.52E-01	7.68E-01
Food products, beverages and tobacco	5.24E-02	6.18E-02
Textiles, textile products, leather and footwear	5.67E-02	6.68E-02
Wood and products of wood and cork	1.41E-01	1.66E-01
Paper products and printing	4.52E-02	5.33E-02
Coke and refined petroleum products	2.97E-03	3.49E-03
Chemical and chemical products	2.83E-02	3.34E-02
Pharmaceuticals, medicinal chemical and botanical products	5.89E-02	6.94E-02
Rubber and plastics products	3.84E-02	4.52E-02
Other non-metallic mineral products	1.63E-02	1.92E-02
Basic metals	6.60E-03	7.78E-03
Fabricated metal products	6.01E-03	7.07E-03
Computer, electronic and optical equipment	4.48E-02	5.28E-02
Electrical equipment	1.33E-02	1.57E-02
Machinery and equipment, nec	1.03E-02	1.22E-02
Motor vehicles, trailers and semi-trailers	4.15E-03	4.89E-03
Other transport equipment	1.49E-02	1.76E-02
Manufacturing nec; repair and installation of machinery and equipment	1.08E-02	1.27E-02
Electricity, gas, steam and air conditioning supply	3.50E-03	4.12E-03

	Value	Unit
Equivalence	1	USD
	0.8488	€

Jobs coefficients (f) are calculated according to the steps outlined in the 'Introduction' sheet. To convert the monetary unit to €, a factor of 0.8488 is used for 2018. However, this factor should be adjusted based on the reference year.

Figure 21. Example of job coefficient calculation for Spain and year 2018.

3.6 Life Cycle Costing indicators

3.6.1 Overview of the method

A series of LCC indicators were selected for the purpose of evaluating the economic profitability of the case studies of the CALIMERO project. In this sense, a manufacturer perspective was considered to account for the economic profitability. A more detailed description of the methodology appears is documented in **D3.5**.

3.6.2 Methodology availability

To facilitate its application an Excel calculator tool was developed to facilitate the uniform application of the same formulas and procedures, which is publicly available as Annex B (Life Cycle Costing indicators calculator tool) in **D3.5**. The tool can be also downloaded from CALIMERO website.

3.6.3 Practical application steps

A description of the steps needed to follow for using the tool is provided:

- Step 1. Go to the CALIMERO website: https://calimeroproject.eu/ and click on the "Knowledge centre" drop down menu and select "Documents" (see **Figure 22**). Go to the "Tools" section and download the Excel file "Annex B. Life Cycle Costing indicators calculator tool".

Figure 22. "Documents" section of the CALIMERO project website.

- Step 2. Once the Excel file is downloaded, open it and take a look at the Introduction tab. Here you will find a brief introduction to the LCC methodology and the economic indicators included. It also describes the instructions to follow, so be sure to read them (see **Figure 23**).

Annex B. Life Cycle Costing indicators calculator tool

Introduction

Life Cycle Costing (LCC) is the economic counterpart of Life Cycle Assessment (LCA). There are three different ways of evaluating the costs over the life cycle of products: conventional (cLCC), environmental (eLCC) and social (sLCC). Of these, the cLCC was selected to propose a set of indicators from the perspective of a manufacturing company, with the aim of being included in the economic assessment of the CALIMERO project.

In this context, the following economic indicators have been proposed to be estimated:
- Life Cycle Cost (LCC)
- Net Present Value (NPV)
- Levelized Cost of Production (LCoP)
- Internal Rate of Return (IRR)
- Payback Period (PP)
- Environmental externalities

In addition, two different scenarios have been proposed as hypothetical examples to facilitate the application task.

Figure 23. "Introduction" tab of the Life Cycle Costing indicators calculator tool.

- Step 3. To evaluate the economic indicators for your case study, take one of the pre-defined case studies, i.e., "Case study 1" or "Case study 2", and modify it to include your specific data.

- Step 4. Using "Case study 1" as an example to modify, look at the legend of the cells. In this case, modify the green cell (Description) to describe the starting situation of your case study in terms of the time frame considered, if there is any Capital Expenditure (CAPEX) during these years, among any other type of information you may consider including (see **Figure 24**).

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Legend

Cell	Meaning
	Title
	Description
	Editable value
	Not editable value
	Final value

Case study 1

Starting situation

Scenario with a time frame of 10 years, CAPEX in year 1, as well as OPEX and sales every year.

Figure 24. Legend and description of the starting situation for the "Case study 1".

- <u>Step 5</u>. Now focus only on the list of orange cells (editable values) and fill them according to the data you have and the indicator you want to evaluate, in terms of Operational Expenditure (OPEX), CAPEX, maintenance rate, depreciation rate, discount rate, inflation rate, taxes, CO_2 emissions, CO_2 price, sales and FU (see **Figure 25**). Regarding the modification of the time frame, consider that it is necessary to manually modify the Excel to include or reduce the number of years covered. In both case studies, a time frame of 10 years is considered. Please, take into consideration maintaining the units provided for each of these values for obtaining plausible results.

Variable	Value	Unit
Time frame	10	years
OPEX	-1,898.00 €	€
CAPEX	-53,799.00 €	€
Maintenance rate	5%	%
Depreciation rate	10%	%
Discount rate (i)	5%	%
Inflation rate	3.1%	%
Taxes	25%	%
CO_2 emissions	0.05	ton CO_2 eq.·FU^{-1}
CO_2 price	75.00	€·ton CO_2 $eq.^{-1}$
Sales	25,391.93 €	€·$year^{-1}$
Functional Unit (FU)	52.14	L·$year^{-1}$

Figure 25. Table for the editable values (orange cells) given by default for the "Case study 1".

- <u>Step 6</u>. Take a look at the results obtained in the "Economic indicators" section, where in the purple cells (Not editable value) are represented the value for the LCC, Net Present Value (NPV) and Levelized Cost of Production (LCOP), while in the yellow cells (Final values) are the figures obtained for the Internal Rate of Return (IRR), the environmental externalities in terms of CO_2 emissions, as well as the Payback Period (PP) (see **Figure 26**).

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Economic indicators

	Year (t)											
	1	2	3	4	5	6	7	8	9	10	Total	
Life Cycle Cost (LCC)	-55,606.62 €	-7,877.45 €	-7,716.89 €	-7,560.10 €	-7,406.97 €	-7,257.38 €	-7,111.24 €	-6,968.45 €	-6,828.92 €	-6,692.55 €	-121,026.58 €	
	45.95%	6.51%	6.38%	6.25%	6.12%	6.00%	5.88%	5.76%	5.64%	5.53%		
	Year (t)											
	1	2	3	4	5	6	7	8	9	10	Total	Per FU
Net Present Value (NPV)	-31,423.83 €	15,867.75 €	15,598.63 €	15,333.52 €	15,072.39 €	14,815.21 €	14,561.94 €	14,312.55 €	14,066.99 €	13,825.25 €	102,030.38 €	26.52 €

	Year (t)	Per FU
	10	
Levelized Cost of Production (LCOP)	1,790.43 €	34.34 €

	Year (t)
	10
Internal Rate of Return (IRR)	54.86%

	Per FU
Environmental externalities	3.60 €

	Total investment (€·year^{-1})	Average cash flow (€)	Year (unrounded)	Year (rounded)
Payback Period (PP)	53,799.00 €	14,626.36 €	3.68	4.00

Figure 26. Values obtained for the economic indicators selected for the "Case study 1".

- <u>Step 7</u>. After this, it is recommended to look at the "Variables" and "LCC Indicators and equations" tabs for further understanding within the reasonable of the equations and variables used in each of the economic indicators.

3.7 Novel toxicity characterization factors: ProScale

3.7.1 Overview of the method

ProScale is a life cycle-oriented method designed to assess toxicological potentials of chemicals in product systems. It can be distinguished two different aspects of this method: ProScale H and ProScale E. ProScale H focuses on direct exposure related human toxicity while ProScale E is designed for ecotoxicity potential assessment. Within the CALIMERO project no development of ProScale as a method was performed, but CFs for relevant substances were calculated to simplify the use of LCIA methods for toxicity. In deliverable **D3.5** CFs for ProScale H considering workers exposure were calculated, while CFs for ProScale E were calculated in deliverable **D3.1**.

3.7.2 Methodology availability

The method was first published in 2017 and its available as a guidance document and associated Excel calculation sheet, as well as a webtool with a database of processes under development (https://proscale.org/projekt/proscale/research-and-test-cases.html).

3.7.3 Practical application steps

- **<u>ProScale H</u>**

To apply ProScale to a defined FU, the life cycle of the product has to be defined with its different unit processes. In each unit process the substances used as raw materials, produced as product and contained are considered.

For each substance and each unit process, ProScale combines information about the substance such as toxicological properties, the specific exposure determined by the physical properties of the substance and the defined exposure conditions, the time of exposure, the population exposed and the quantity of substance used. This is done for all substances in all unit processes so that the scores for all substances can be consolidated to determine the ProScale assessment score at the required level of aggregation. This is reflected in **Equation 2**, where the ProScale of Unit Process (PSU H) is derived based on the Hazard Factor (HF), Exposure Concentration Factor (ECF), Person-Hours Factor (PHF), and Mass Flow (MF) for a specific substance, *i*, and unit process, *u*. As the other parameters in the total ProScale score are process specific, CFs are derived from only the HF which is substance specific.

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$$PSU\ H_{u,route} = \sum_i \underbrace{HF_{i,route}}_{\text{CF}} \cdot ECF_{i,u,route} \cdot PHF_u \cdot MF_{i,u} \quad (2)$$

- Hazar Factor (HF): Describes the hazard of a substance in ProScale, reflecting health effect severity and potency. The HF of a substance shall be established separately for each exposure route (dermal, inhalation, oral), resulting in hazard factors which may be different for each of the three routes. The HF is based on two input data; the substance hazard statement (H-phrase) and the Occupational Exposure Limits (OEL) or Derived No-Effect Levels (DNEL) when OELs are not available.

- Exposure Concentration Factor (ECF): Refers to the potential concentration that a person is exposed to during a specific process or activity. To estimate the ECF is modelled via ECETOC Targeted Risk Assessment (TRA) Tier 1 approach.

- Person-Hours Factor (PHF): Number of person-hours of exposure per mass unit of produced product, service or process. For production processes, the PHF is calculated as a function of annual hours worked and annual production volume.

- Mass Flow (MF): Amount of substance needed to produce a product (per functional unit). The MFs are calculated by multiplying the mass of the functional unit with the mass fraction of the substance used or produced in a unit process.

- Step 1**:** Data collection

For a ProScale H assessment the main source of data apart from common LCI data is Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) Registered Substances Factsheets the European Chemicals Agency (ECHA) website. The LCI data is used to identify the MFs of inflow and outflows of material and emissions from each unit process in the assessed lifecycle, while the REACH Factsheets are used to collect hazard phrases (H3XX-phrases), DNELs (if no OELs are available), and if needed vapour pressure/dustiness and process categories (PROCs).

The hierarchy for collection of H-phrases is as follow:

1. Disseminated information from the REACH dossiers available via ECHA website

2. Harmonized CLP classification (CLP Annex VI).

3. Notified CLP classification from ECHA website considering the 1st row (joint entry or entry with the most notifications).

4. SDS from the supplier.

For collection of OELs and DNELs the following hierarchy is applied:

1. German OEL TRGS900

2. TLV value

3. European OEL

4. Dutch OEL

5. DNEL from REACH dossier

- Step 2: Calculations with ProScale H

The collected data should be inserted into the ProScale H webtool (https://proscale.org/projekt/proscale/tools.html) or spreadsheet. By inserting the data in the ProScale template, both HFs and ECFs factors are obtained. Underlying models can modify the ECF if the tool operator has knowledge about risk management measures (RMMs) for the unit processes in question. The PHF can either be calculated based on specific data on annual hours work and the annual production volume for a unit process, or default PHFs can be selected. Once all input data is provided a final ProScale value based on the HF, ECF and PHF for the substances in the unit process are calculated, which are multiplied with the MFs of inputs and outputs from the LCI to derive the ProScale score for each unit process. The total ProScale score of a life cycle of a product as so called ProScale of Product (PSP) is derived by summarizing the ProScale scores for all substances and unit processes included in the life cycle as in **Equation 3**.

$$PSP\ H_{route} = \sum_{u}\sum_{i}(HF_{i,route} \cdot ECF_{i,u,route} \cdot PHF_{u} \cdot MF_{i,u}) \quad (3)$$

In cases where suitable data is unavailable prediction tools may be used. For more details on the calculation procedures see the ProScale Documentation[1].

Additional characterization factors

A total of 52 CFs could be calculated based on H-phrases, OELs and DNELs from REACH dossiers found at the ECHA website. By utilizing H-phrase predictions it was possible to calculate additional CFs, see **Table 8**. For the remaining substances of interest, it was impossible to calculate characterization factors due to missing data or negative H-phrase predictions.

Note that to apply these CFs for LCA calculations additional parameter data is required, e.g., the PHF.

Table 8. ProScale Characterization Factors (CFs). *Substances completely based on "likely positive" H-phrases predictions, **Substances partly based on "likely positive" H-phrases predictions.

Chemical name	CAS	ProScale CF		
With H-phrases from ECHA		Inhalation	Dermal	Oral
Boric acid	10043-35-3	6.23E+00	0.00E+00	0.00E+00
Calcium chloride	10043-52-4	3.16E+00	3.16E+01	0.00E+00
4,4'-Diisocyanatodiphenylmethane	101-68-8	1.00E+04	1.00E+04	1.00E+04
Nitric oxide	10102-43-9	1.00E+04	1.00E+03	0.00E+00
Ceric sulfate tetrahydrate	10294-42-5	0.00E+00	1.00E+03	0.00E+00
Butyric acid	107-92-6	1.76E+01	1.76E+02	1.76E+01
Diisobutyl ketone	108-83-8	1.58E+01	0.00E+00	0.00E+00
Cyclohexane	110-82-7	1.00E+00	1.00E+01	1.00E+02
2-Phenoxyethanol	122-99-6	1.27E+01	1.27E+02	1.27E+01
Flumexol WDN	126-71-6	1.61E+00	1.61E+02	0.00E+00

[1] Lexén, J., Belleza, E., Loh Lindholm, C., Rydberg, T., Amann, N., Aschford, P., Bednarz, A., Coërs, P., Dornan, P., Downes, R., Enrici, M. H., Glöckner, M., Gura, E., de Hults, Q., Karafilidis, C., van Miert, E., Saling, P., Tiemersma, T., Wathelet, A., & Wienbeck, X. (2021). ProScale: A life cycle oriented method to assess toxicological potentials of product systems (2017): Guidance document, version 1.5. https://urn.kb.se/resolve?urn=urn:nbn:se:ivl:diva-3844

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Boric oxide	1303-86-2	1.00E+05	1.00E+05	1.00E+05
Sodium tetraborate decahydrate	1303-96-4	1.00E+05	1.00E+05	1.00E+05
Calcium hydroxide	1305-62-0	5.08E+01	5.08E+02	0.00E+00
Calcium oxide/Lime/Quicklime	1305-78-8	5.08E+01	5.08E+02	0.00E+00
Potassium hydroxide	1310-58-3	0.00E+00	1.00E+03	1.00E+02
Caustic soda	1310-73-2	0.00E+00	1.00E+03	0.00E+00
Sodium oxide	1313-59-3	0.00E+00	1.00E+03	0.00E+00
Monoethanolamine	141-43-5	3.14E+01	3.14E+02	3.14E+01
Ethyl acetate	141-78-6	1.00E+00	1.00E+01	0.00E+00
Chemical name	**CAS**	**ProScale CF**		
With H-phrases from ECHA		**Inhalation**	**Dermal**	**Oral**
Polyethylene glycol dimethyl ether	24991-55-7	1.00E+05	1.00E+05	1.00E+05
Methylisothiazolinone	2682-20-4	1.00E+04	1.00E+03	1.00E+03
Sodium Carbonate	497-19-8	1.00E+01	1.00E+02	0.00E+00
Formaldehyde	50-00-0	2.27E+04	2.27E+04	2.27E+04
Toluene diisocyanate/Toluene, 2,4-diisocyanate	584-84-9	1.00E+04	1.00E+03	0.00E+00
Ethylenediaminetetraacetic acid	60-00-4	4.51E+01	0.00E+00	0.00E+00
Cobalt acetate	6147-53-1	1.00E+05	1.00E+05	1.00E+05
Ethanol	64-17-5	1.00E+00	1.00E+01	0.00E+00
Acetic acid	64-19-7	1.97E+00	1.97E+02	0.00E+00
Prestogen FCB	6419-19-8	0.00E+00	1.00E+02	0.00E+00
Hydroxymethylfurfural (HMF)	67-47-0	1.00E+02	1.00E+03	0.00E+00
Methanol	67-56-1	1.00E+02	1.00E+02	1.00E+02
Acetone	67-64-1	1.00E+00	1.00E+01	0.00E+00
Chloroform	67-66-3	3.88E+03	3.88E+03	3.88E+03
Benzenesulfonic acid, C10-13-alkyl derivs., sodium salts	68411-30-3	2.80E+00	2.80E+02	2.80E+01
Butanol	71-36-3	1.00E+01	1.00E+02	1.00E+01
Ethylene	74-85-1	1.00E+01	0.00E+00	0.00E+00
Nickel	7440-02-0	1.00E+04	1.00E+04	1.00E+04
Dichloromethane	75-09-2	1.10E+03	1.10E+03	1.10E+03
Hydrochloric acid	7647-01-0	3.68E+02	3.68E+02	0.00E+00
Phosphoric acid	7664-38-2	4.14E+00	4.14E+02	4.14E+01
Ammonia	7664-41-7	2.34E+02	2.34E+02	0.00E+00
Sulphuric acid	7664-93-9	1.00E+01	1.00E+03	0.00E+00
Sodium hypochlorite	7681-52-9	4.46E+00	4.46E+02	0.00E+00
Disodium disulphite	7681-57-4	1.03E+00	1.03E+02	1.03E+01
Sulphur	7704-34-9	0.00E+00	1.00E+02	0.00E+00
Iron sulfate	7720-78-7	0.00E+00	1.00E+02	1.00E+02
Potassium Permanganate	7722-64-7	8.15E+00	8.15E+02	8.15E+01
Hydrogen peroxide	7722-84-1	4.60E+01	4.60E+02	4.60E+01
Sodium persulfate	7775-27-1	5.38E+03	5.38E+02	5.38E+01
Chlorine	7782-50-5	4.51E+02	4.51E+01	0.00E+00
Diisocyanates	822-06-0	1.00E+04	1.00E+03	0.00E+00
Cellulase	9012-54-8	1.00E+04	0.00E+00	0.00E+00
Chemical name	**CAS**	**ProScale CF**		
With predicted H-phrases		**Inhalation**	**Dermal**	**Oral**

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Triethanolamine**	102-71-6	1.00E+05	1.00E+05	1.00E+05
Carbon dioxide	124-38-9	3.33E+03	3.33E+03	3.33E+03
Sodium oxide	12401-86-4	0.00E+00	1.00E+03	0.00E+00
Gypsum**	13397-24-5	1.00E+04	1.00E+04	1.00E+04
(2-methoxymethylethoxy)propanol*	34590-94-8	0.00E+00	1.00E+03	0.00E+00
Urea**	57-13-6	1.00E+05	1.00E+05	1.00E+05
Dimethyl sulfoxide**	67-68-5	1.00E+05	1.00E+05	1.00E+05
Boron	7440-42-8	1.00E+05	1.00E+05	1.00E+05
Sodium Chloride	7647-14-5	0.00E+00	1.00E+03	1.00E+04
Ammonium sulfate*	7783-20-2	0.00E+00	1.00E+03	0.00E+00

- **ProScale E**

ProScale E CFs are calculated with a simple formula based on the HF and Degradation Factor (DF). For a complete ProScale E score for a unit process, a ProScale of Unit Process (PSU E), the CF is multiplied with the emission flow to each environmental compartment, which can be described by the MF, and the Environmental Release Factor (ERF) for each substance, *i*, to every relevant environmental compartment, *c*, for a unit process, *u*. In **Equation 4**, PSP E is presented.

$$PSP\ E_c = \sum_u \sum_i (\underbrace{HF_i \cdot DF_i}_{\text{CF}} \cdot MF_i \cdot ERF_{i,c}) \qquad (4)$$

- Hazard Factor (HF): For ProScale E the HF also describes the hazard of a substance. Similarity, to the HF for ProScale H the HF for ProScale E is assigned based on two input data, the substance hazard statement (H-phrase) and the multiplying factor (M-factor) but for the H4XX-phrases.
- Degradation Factor (DF): The DF captures the persistence of a substance in the environment and is established based on the biodegradation in water and persistence assessments.
- Mass Flow (MF): See section on ProScale H.
- Environmental Release Factor (ERF): A factor for derivation of emissions based on the input and output MFs. Note that for unit processes where emission flows for some substances are known the MF and ERF can be replaced or used as complimentary for other emission flows.

The model for ProScale E is a recent addition of the ProScale methodology; thus, no tools or ready-made spreadsheets are available and additional development of the tool is expected.

- Step 1: Data collection and calculations with ProScale E

As with ProScale H the main sources of data are the LCI and REACH registration dossiers from ECHA, but for ProScale E, the H4XX-phrases, M-factors, degradation in water and persistence are collected instead. In cases where the LCI data cover emissions of chemicals, the data can be used to replace the MF and ERFs, while in cases where emissions are suspected to be missing or lacking from the LCI, different ways to derive the ERFs are possible. One way suggested is to use Emission Release Categories (ERCs) or Specific Environmental Release Categories (spERCs) provided by ECHA or industrial sectors as replacements for the ERFs (European Chemicals Agency, 2016). Other tools for modelling of emission may also be suitable.

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The current procedure for the collection of H4XX-phrases is to extract any relevant H-phrase and M-factors from lead joint submissions of dossiers, with priority to full registrations over intermediates ones, on the ECHA CHEM website (https://chem.echa.europa.eu/). If no H-phrases are available, the use of prediction tools for H-phrases and M-factors and calculated M-factors from measured data is suggested. A tool that can be used is for H-phrase predictions is provided in the Mistra SafeChem toolbox (Norinder et al., 2025.). The preferred hierarchy is as follows:

1. H-phrase available in ECHA CHEM + Collected M-factor from ECHA CHEM
2. Predicted H-phrase + Calculated M-factors
3. Predicted H-phrase + Predicted M-factors

When the H4XX-phrases and corresponding M-factors has been collected, **Table 9** is used for harmonization of HFs.

Table 9. Table for derivation of the hazard factor (HF) from H-phrases and M-factors.

ProScale hazard class	CLP hazard categories (4XX-phrases)	Environmental hazard factor (HF_e)
E (10 000 - 100 000)	PBT/vPvB	100 000
	PMT/vPvM	100 000
	ED, env cat 1	100 000
	Chronic aquatic 1 (H410), M-factor ≥ 10 000	100 000
	Chronic aquatic 1 (H410), M-factor = 1000	30 000
D (1000 - 10 000)	ED, env cat 2	10 000
	Chronic aquatic 1 (H410), M-factor = 100	10 000
	Acute aquatic (H400), M-factor ≥ 10 000	10 000
	Chronic aquatic 1 (H410), M-factor = 10	3000
	Chronic aquatic 1 (H410), M-factor = 1	1000
	Acute aquatic (H400), M-factor = 1000	3000
C (100 - 1000)	Chronic aquatic 2 (H411)	1000
	Acute aquatic (H400), M-factor = 100	1000
	Acute aquatic (H400), M-factor = 10	300
B (10 - 100)	Chronic aquatic 3 (H412)	100
	Acute aquatic (H400), M-factor = 1	100
A (1 - 10)	Chronic aquatic 4 (H413)	10
No hazard	No class ("regarded as safe")	-

For degradation in water, information is to be collected from the section "5.2.1 Biodegradation in water: Screening test" in the REACH registration dossiers, while persistence is collected from the section "2.3 PBT assessment" and harmonized based on **Table 10**. Note that the current procedure for inorganics is to assign DF = 1 no matter the reported statements on degradation and persistence – however this may be revised in future model updates. If no data on degradation and persistence is available prediction tools may be used.

Table 10. Table for derivation of the degradation factor (DF).

Degradation factor (DF)

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Readily biodeg	0.01
Inherently/Rapidly biodeg	0.1
Persistent/Not biodeg	1
Very persistent	
Inorganic substance*	

*Note that the assigning of DF = 1 to inorganics may be revised in the future.

Additional characterization factors

The CFs calculated for ProScale E are presented in **Table 11**, in total 31 substances have a CF. The remaining substances are, in the current version of ProScale E, “regarded as safe”, but users should be aware that the underlying data may be incomplete, and all CFs are considered interim due to difficulties relating to data availability (see discussion in **D3.1**).

*Table 11. Interim ProScale E characterization factors. Substances which have H4XX-phrases in ECHA CHEM has been marked with *, the remaining CFs are calculated based on predictions. “-“ indicates that no CFs could be calculated.*

Chemical Name	CAS	ProScale E CF
Boric acid	10043-35-3	1000
Calcium chloride	10043-52-4	-
4,4'-Diisocyanatodiphenylmethane	101-68-8	1000
Nitric oxide	10102-43-9	1000
Triethanolamine	102-71-6	-
Ceric sulfate tetrahydrate*	10294-42-5	1000
Butyric acid	107-92-6	-
Diisobutyl ketone	108-83-8	-
Dipotassium phosphate	7758-11-4	-
Cyclohexane*	110-82-7	10
Borax pentahydrate	12179-04-3	-
2-Phenoxyethanol	122-99-6	-
Carbon dioxide	124-38-9	-
Sodium oxide	12401-86-4	-
Flumexol WDN*	126-71-6	1
Cobalt Molybdenum Alloy	12604-58-9	-
Boric oxide	1303-86-2	-
Sodium tetraborate decahydrate	1303-96-4	-
Calcium hydroxide	1305-62-0	-
Calcium oxide/Lime/Quicklime	1305-78-8	-
Potassium hydroxide	1310-58-3	-
Caustic soda	1310-73-2	-
Sodium oxide	1313-59-3	-
Zinc oxide*	1314-13-2	1000
Zirconium dioxide	1314-23-4	-
H-Mordenite	1318-02-1	-
Zeolite	1318-02-1	-

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Gypsum	13397-24-5	-
Aluminum oxide	1344-28-1	-
Monoethanolamine*	141-43-5	1
Ethyl acetate	141-78-6	-
Aluminium hydroxide	21645-51-2	-
Polyethylene glycol dimethyl ether	24991-55-7	-
Poly(oxy-1,2-ethanediyl),α-hydro-ω-hydroxy- Ethane-1,2-diol, ethoxylated	25322-68-3	-
Methylisothiazolinone*	2682-20-4	1000
Tungstic acid	7783-03-01	-
Tris (2.4-ditert-butylphenyl)	31570-04-4	-
(2-methoxymethylethoxy)propanol	34590-94-8	-
Calcium carbonate	471-34-1	-
Sodium Carbonate	497-19-8	-
Formaldehyde	50-00-0	-
Glucose	50-99-7	-
Rucholase HCH	56-81-5	-
Urea	57-13-6	-
Toluene diisocyanate/Toluene, 2,4-diisocyanate*	584-84-9	100
Platinum	7440-06-04	-
Ethylenediaminetetraacetic acid	60-00-4	-
Cobalt acetate*	6147-53-1	3000
Ethanol	64-17-5	-
Acetic acid	64-19-7	-
Prestogen FCB	6419-19-8	-
Hydroxymethylfurfural (HMF)	67-47-0	-
Methanol	67-56-1	-
Acetone	67-64-1	-
Chloroform	67-66-3	-
Dimethyl sulfoxide	67-68-5	-
Benzenesulfonic acid, C10-13-alkyl derivs., sodium salts*	68411-30-3	1
Molasses	68476-78-8	-
Isotridecanol, ethoxylated/Poly(oxy-1,2-ethanediyl), α-tridecyl-ω-hydroxy-, branched*	69011-36-5	1
Butanol	71-36-3	-
Methane	74-82-8	-
Ethylene	74-85-1	1
Nickel*	7440-02-0	100
Boron	7440-42-8	-
Magnesium sulfate	7487-88-9	-
Dichloromethane	1975-09-02	-
Hydrochloric acid	7647-01-0	100
Sodium Chloride	7647-14-5	-
Phosphoric acid	7664-38-2	-
Ammonia*	7664-41-7	1000

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Sulphuric acid	7664-93-9	-
Sodium hypochlorite*	7681-52-9	100
Disodium disulphite	7681-57-4	-
Sulphur	7704-34-9	100
Iron sulfate	7720-78-7	-
Potassium permanganate*	7722-64-7	3000
Hydrogen peroxide*	7722-84-1	100
Sodium persulfate	7775-27-1	-
Chlorine*	7782-50-5	1000
Ammonium sulfate	7783-20-2	-
Diammonium phosphate	7783-28-0	-
Diisocyanates	822-06-0	1000
2,6-Bis(2-isocyanato-3-((2-isocyanatophenyl)methyl)benzyl)phenyl isocyanate	85423-11-6	3000
Hexane, 1,6-diisocyanato-	88357-62-4	-
Sulfur dioxide	7446-09-5	-
Octadecane -1-ol ethoxylated*	9005-00-9	10
Cellulase	9012-54-8	-
Glucoamylase	9032-08-0	-
Kieralon MWF (hostapal MWF, soap)	9043-30-5	-
1,1,1-Tris(4-cyanatophenyl)ethane	N/A	300
(2Z)-2-[(10E)-10-[cyano(isocyano)methylidene]-3-(3-methyloxiran-2-yl)-2,7,8-tris(oxiran-2-yl)-4b,9b-dihydroindeno[2,1-a]inden-5-ylidene]-2-isocyanoacetonitrile	N/A	3000
2,2'-Methylenebis(6-(o-isocyanatobenzyl)phenyl) diisocyanate (C31H20N4O4)	85392-14-9	1000
2,6-Bis(o-isocyanatobenzyl)phenyl isocyanate (C23H15N3O3)	21132-81-0	1000
Alcohols, C16-18, ethoxylated*	68439-49-6	10
Amylase	9000-90-2	-
Anionic polyacrylamide	9003-0-8	-
Fatty alcohol ethoxylate	78330-20-8	1000
Fodder yeast	8013-01-02	-
Formic acid (CH2O2)	64-18-6	-
Lubricating oil	74869-20-0	-
Polyaluminium chloride	1327-41-9	-
Polyester copolymer	139755-78-5	-
Propionic acid (C3H6O2)	79-09-04	-
Sodium hydroxide	215-185-5	-
Sulfuric acid	7664-93-9	-

3.8 Novel toxicity characterization factors: UseTox

3.8.1 Overview of the method

To evaluate the potential environmental impacts of a chemical substance used in a process by means of the UseTox method it is necessary to: 1) quantify the mass being released of this chemical substance and that of related transformation/degradation products into the environment; 2) quantify the associated environmental

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impact using a specific CF[2].

1) Quantify the compounds and mass being released.

1.1 Identifying the compounds (chemical substance and transformation products) emitted.

Often a chemical substance used in the production process (e.g., washing of a textile or glueing of plywood) are not equal to the chemicals emitted by the process, as the initial chemical will change in different reaction products (transformation/degradation products). The proper identification of those transformation products will allow to precisely characterize the environmental impacts associated with the use of an input chemical.

The list of chemicals used in each case study should be first screened for any corresponding transformation products. For the textile case studies this was done using the list of transformation products provided in the Supplementary Material of (Roos et al., 2019) (note that this article is open access and the supplementary material can be found in the same link). Similarly, a literature search for the relevant industrial sector could allow for the identification of potential transformation products associated with other sectors.

If the modelled chemical substance does not generate transformation products, but it is directly emitted as such to the environment, or no literature sources can be identified, then the basic assumption will be that the initial input chemical substance is also present in the process emissions. Therefore, if there is no information available on transformation products, the chemical substance can simply be considered.

1.2 Identifying the amounts emitted to certain compartments (e.g., air, water, soil, etc.).

After having identified the types of compounds emitted, the emission amounts to certain compartments should be estimated. The mass of chemical emitted to the environment will depend on the industrial sector and production process under study. For example, for textile there are both air emissions and water emissions of chemical substances; while for woodworking, the emissions are mainly air emissions from the pressing process. Assumptions must be made to model the mass of chemical substance being emitted to the environment. The textile case study uses the assumptions from (Roos et al., 2019) (see **Figure 27**). Although developed for textiles, these factors could also be used for other sectors on a case-to-case basis. For other sectors, the emissions can be based on the optimization modeling results or literature search.

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[2] If this amount is omitted during the life cycle assessment stage, then its impacts on the environment and people will not be characterized. In addition, if the given chemical substance (elementary flow) does not have an associated CF for the given impact category, the associated potential environmental impact will not be characterized.

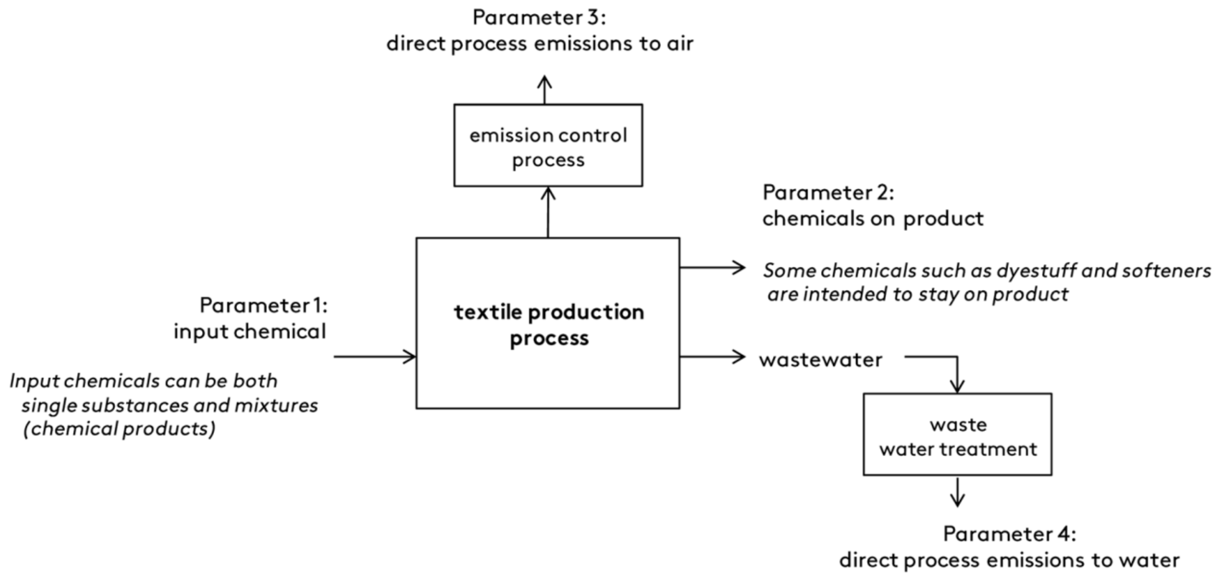

Figure 27. Overview of emission parameters considered for chemicals in the textile sector (with implicit consideration of transformation products), copied from (Roos et al., 2019), serving as an example for the textile case study addressed in the CALIMERO project.

2) Define the associated environmental impact using CF.

To define the impact, **Equation 5** is used:

$\text{Impact} = \text{Emitted amount (mass)}\ of\ compound\ X\ to\ compartment\ Y \cdot CF\ of\ compound\ X\ for\ compartment\ Y$	(5)

The CFs to add are mainly for the following impact categories: Ecotoxicity, freshwater and Human toxicity (non-cancer) both water and air emissions. In addition, for compounds emitted to air, we advise to pick the “industrial air” compartment.

3.8.2 Methodology availability

It is worth nothing that this does not necessarily need to be done in LCA software, you can do this simple multiplication yourself with Excel. For the chemical substance, the CF should either be provided by the environmental footprint method or has been developed by LIST (see **D3.5**). For the transformation products, LIST has not developed dedicated CFs, but these can be found either in the Environmental Footprint method or possibly in literature.

3.8.3 Practical application steps

The procedure to include novel CFs of chemical substances used in an industrial process, following the UseTox approach, is outlined below distinguished by applying by means of a dedicated life cycle software and for the particular case of SimaPro:

Operational Procedure for software

- Step 1. In your software, add to your product system or to the specific production process, the type and quantity of chemical substances that have been identified as being emitted. Those elementary flows should be added as directs outputs to the biosphere. Search for either the transformation

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products or the initial input chemical substance. The chemical of interest should be already included in the biosphere dataset of your software.

- Step 2. If the chemical substance is not present, then this must be added as a new elementary flow to the biosphere. Create a new elementary flow by adding the chemical name and the CAS number of the chemical in the biosphere dataset in your software.

- Step 3. After having added the chemical substance to the biosphere as elementary flow, add the CF for the given impact category. For eco and human toxicity, the CF have been provided by LIST in the WP3 work. Those should be added to the method of your software, so to quantify the impacts in terms of Ecotoxicity, freshwater and Human toxicity, non-cancer. The new CFs must be added directly to the impact assessment method (Environmental Footprint) in your software.

Operational Procedure specific for SimaPro modelling

- Step 1. Open the process activity in which the chemicals are being used or the product system of your activity. In the outputs section you will have to add all the direct elementary flows to the environment, indicated as Emissions to air, Emissions to water, Emissions to soil.

- Step 2. Type to search or scroll the list of substances shown. Check the matching substance by verifying the CAS number. If the substance is already present in the list, click unspecified for the sub-compartment selection and then click select to add the elementary flow in the process activity.

- Step 3. Assign the corresponding mass to the elementary flow according to the emissions scenarios that have been defined by the optimization modeling or by literature search as discussed above.

- Step 4. Run your impact assessment

If the substance is not already included in the elementary flows list, then this means that it is not present and must be manually added.

- Step 5. In the Methods tab make a copy of the EF3.1 method (make sure to use a different name for the copy).

- Step 6. Open the new copy using the Edit button.

- Step 7. Click on the “Characterization” tab. In this tab you will see the list of all elementary flows to all the environmental compartments for each environmental impact category. We are only interested in the Toxicity impacts (both eco and human).

- Step 8. Select the impact category Ecotoxicity, freshwater – part 2, this will open a list of all elementary flows related to the ecotoxicity impacts. Select “Add” (the one in the middle of the page) to add a new substance to the list of elementary flows, then select the main compartment of emissions, waterborne emissions, then select “New”.

- Step 9. Add the new substance name and CAS number. This will add the substance to the list, double click on it, this should point you to where to insert the CF value for freshwater ecotoxicity from water emissions.

- Step 10. Repeat the same procedure for Human toxicity, non-cancer and select “Airborne emissions” as main compartment.

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3.9 Occupational Exposure Limits indicator

3.9.1 Overview of the method

Occupational Exposure Limits (OEL) indicator has been developed during the CALIMERO project. The aim of the indicator is to evaluate, exposure risks and implement measurements to minimize and/or eliminate the exposure risks, into social performance assessments. The indicator can be used as a stand-alone indicator or can be integrated into Health and Safety refence scales covering several indicators.

3.9.2 Methodology availability

A more detailed description is given in D3.5.

3.9.3 Practical application steps

The steps for using the indicator as a stand-alone indicator is explained below.

- Step 1. Adopt the below reference scale to evaluate the OEL indicator (**Table 12**). This scale is a 5-level scale, according to your study conditions (country, sector etc.), and the expected compliance with local and international laws which defines level 0. You can choose another type of scale and revise the levels.

Table 12. Scale level to evaluate the OEL indicator

Scale level	Description
+2	Level A. Work to eliminate risk (i.e., remove exposure or the culprit chemical) is present.
+1	Level B. Efforts to implement measures that minimize risk for exposure in the work environment are present.
0	Level C. Prevalent chemical health risks in the work environment are monitored and new risks are systemically identified. In cases where OELs values exist, measurements are carried out and the work environment is managed so that limit values are complied with.
-1	-
-2	-

- Step 2. Using the list of the questions below, make interviews with at least three people from the site. The roles in the facility of investigation might be from health and safety, production, human resources or other relevant units. Also make interviews with workers and/or union representatives to capture workers point of view on the topic. Each question is prepared related to a level (A, B, C), which are indicated at the end of the questions.

    1. How does the company monitor the risk for exposure to chemicals in the work environment? (C)
    2. Are there specific protocols or procedures established to handle and control chemical exposures of workers? (C)
    3. Are there routines to identify changes in chemical use? (C)

4. Is there exposure to chemicals that have an OEL value? (C)

5. How often does the company carry out work environment measurements to control and monitor exposure with regard to limit values? (C)

6. What preventive measures are used to manage exposure risk? (B)

7. Do the staff use any Personal Protective Equipment (PPE)? (B)

8. What type of chemical management work is conducted within the company? (A)

9. Are you working to reduce the use of chemicals? (A)

- Step 3. Using the replies of the interviewees to the questions, evaluate where in the reference scale the facility stands.

4 MAIN CONCLUSIONS

In summary, this report emphasizes the necessity of adapting and enhancing current LCSA methodologies to effectively address the challenges posed by the bioeconomy. The CALIMERO project identified specific methodological gaps in up to five distinct bio-based sectors, including biodiversity, dynamic carbon footprint, and socio-economic aspects, among others.

Additionally, the CALIMERO project has not only identified these gaps, but has also developed specific methodological improvements within the LCSA approach. The guidelines proposed in this document, explained in a user-friendly manner, serve as a reference for application across different bio-based systems, depending on the purpose of the study, apart from constituting a first step for policy making to decision-makers.

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