



CO-CREATING BEHAVIORAL CHANGE TOWARDS CLIMATE-SMART FOOD SYSTEMS

D3.1 Sustainability assessment v1

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Authors

First Name	Last Name	Beneficiary
Magdalini	Krokida	NTUA
Christos	Boukouvalas	NTUA
Georgia	Frakolaki	NTUA
Fotini	Drosou	NTUA
Olga	Serifi	KPAD
Andreas	Katsigiannis	KPAD

In case you want any additional information, or you want to consult with the authors of this document, please send your inquiries to: geofrak@chemeng.ntua.gr

Quality Reviewers

First Name	Last Name	Beneficiary
Arno	Rosemarin	SEI
Nelson	Ekane	SEI

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Executive Summary

The aim of BEATLES D3.1 is to provide the sustainability (environmental, economic and social) assessment of a baseline scenario for each UC pilot. The sustainability assessment of the baseline scenarios will form the basis for the comparison with the 5 selected food systems (Use Cases, UCs) with applied the different climate smart (CSA) practices, that will be reported in the next deliverable (D3.2). Within the framework of the integrated Life Cycle Sustainability Assessment LCSA (LCA, s-LCA and LCC), the project will assess the environmental, economic and social implications of each scenario. The necessary data were collected by the UC leaders and any supplementary data were provided by appropriate databases or literature. For the LCA assessment, the ReCiPe 2016(H) method was selected and the software SimaPro was used for the impact assessment. In the most of the baseline scenarios, the diesel use and fertilizer application emerge as primary contributors to environmental burdens. Proposed solutions include reducing diesel dependency through energy credits incentivizing renewable energy adoption, alongside minimizing synthetic fertilizer use. The impacts of the various farming activities, such as dairy, apple orchards, pig farming, onion cultivation, potato cultivation, and more, are detailed, highlighting their contributions to global warming, fossil resource scarcity, water consumption, and other environmental issues. These insights underscore the need for CSA practices to mitigate these impacts, focusing on reducing emissions, optimizing energy use, and improving efficiency in agricultural operations. Profound insights into the social impacts of the studied scenarios were provided by the s-LCA assessment. Despite initial low or very low risk assessments for the relevant impact factors, the comprehensive life cycle approach revealed substantial social impacts in upstream flows. Key factors contributing significantly across all scenarios related with fair salaries, embodied biodiversity footprints and greenhouse gas (GHG) footprints, underscoring the urgent need for targeted interventions to address these critical social issues. Moreover, Theory of Change framework was applied in the ongoing actions of BEATLES project, in order to evaluate the effectiveness of behavioral interventions in instigating shifts and improving overall community performance during the transition. The results showed that there is significant consumer interest in sustainable food production, alongside a varied yet cautiously positive reception from farmers towards the recommendations of the BEATLES project. BEATLES activities proved effective in enhancing awareness and comprehension of fairness and sustainability within value chains. However, there is a potential requirement for more tailored and locally focused information to effectively address specific concerns and enhance participation. Cost-Benefit Analysis (CBA) will be applied on the next deliverable, in order to assess the quantity-quality-cost as well as the environmental costs and benefits from integration of the approaches in a certain geographical area.

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List of Terms and Definitions

Abbreviation	Definition
CAP	Common Agricultural Policy
CAPEX	Capital Expenditure
CBA	Cost-Benefit Analysis
CSA	Climate Smart Agriculture
EU	European Union
FU	Functional Unit
KWIN	KWantitatieve INformatie
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCC	Life Cycle Cost
LCSA	Life Cycle Sustainability Assessment
ISO	International Organization for Standardization
OPEX	Operational Expenditure
PSILCA	Product Social Impact Life Cycle Assessment
s-LCA	Social Life Cycle Assessment
ToC	Theory of Change
UC	Use Case
WP	Work Package

Table 1: Terms and Definitions

1. Introduction

BEATLES is a Horizon Europe project aiming to change the way agri-food systems currently operate and accelerate the systemic and systematic behavioural shift to climate-smart agriculture and smart farming technologies fully aligned with the ambitions of the Farm to Fork and Biodiversity Strategies, and the new CAP at regional and EU levels. Five different food systems representing the major crop and livestock farming systems in Europe (cereals, dairy, stone fruits, livestock, vegetables) in various EU regions (Western, Eastern, Southern and Northern Europe), are studied to account for the diversity in agri-food systems and conditions in the EU. The behavioural insights are used to develop transformative pathways, via business strategies and policy recommendations, to encourage transition to fair, healthy and environment-friendly food systems. BEATLES will provide a set of business strategies establishing roadmaps for a fair shift towards climate-smart agriculture, based on environmental, social and economic sustainability assessments.

BEATLES has set up five (5) selected use cases (UCs) across the EU (Lithuania, Germany, Spain, Denmark, Netherlands) that represent diverse food systems in transition to climate-smart agriculture and value chains (wheat, dairy, fruits, pigs, onions and table potatoes) along with various stakeholders across the value chain (farmers, advisors, processors, retailers, investors, consumers, policy makers), indicative of the food systems approach adopted.

Specific Climate Smart Agricultural (CSA) practices will be evaluated within the scope of WP3 regarding their environmental, economic and social impact. The same CSA practices will be assessed throughout WP2, WP3, WP4, and WP5. For this reason, NTUA in collaboration with KPAD and the UC leaders, as well as with the partners from WP2, WP4 and WP5, have selected 5 CSA practices per UC, based on certain criteria, among practices provided in D1.2. The selected CSA practices will be presented in the next deliverable (D3.2), along with their sustainability assessment. NTUA is responsible for the execution of the sustainability assessment of the CSA scenarios per UC and will update and provide the final version of this deliverable by M36 with the support of all partners and especially the KPAD and the UC leaders.

2. Methodology

2.1 Environmental Life Cycle Assessment

2.1.1 Overview of environmental LCA

Life Cycle Assessment (LCA) evaluates the possible environmental effects of products or services across their entire life cycle. This encompasses everything from resource extraction and production to transportation, product use, and end-of-life scenarios such as reuse, recycling, or disposal. Environmental impacts considered may include resource consumption, effects on human health, and ecological ramifications, such as contributions to global warming.

LCA serves as a pivotal tool in enhancing sustainability within supply chains by offering concrete benefits. Firstly, it provides a holistic overview of a product's environmental impacts, allowing for the identification of key areas for improvement throughout its life cycle. This aids in pinpointing hotspots and directing efforts towards enhancing sustainability. Secondly, LCA enables the measurement and monitoring of environmental performance, facilitating the identification of trends and progress over time. By quantifying impacts, organizations can set targets and track their achievements effectively. Moreover, LCA serves as a basis for decision-making, guiding

investments and efforts towards areas with the greatest potential for improvement. Whether in strategic planning or day-to-day operations, the insights gained from LCA inform various aspects of sustainable supply chain management, including strategy development, organizational structuring, product and process innovation, supplier engagement, and marketing strategies.

The International Organization for Standardization (ISO) has standardized the methodology for conducting LCA through its ISO 14040 series of standards. These standards establish principles, frameworks, and methodological requirements for LCA studies. Additionally, the series includes a standardized format for documenting LCA data, as well as two technical reports containing illustrative examples of LCA applications.

2.1.2 Environmental LCA Standardized Methodology

Conducting an LCA study in accordance with the ISO 14040 series of standards comprises four primary phases.

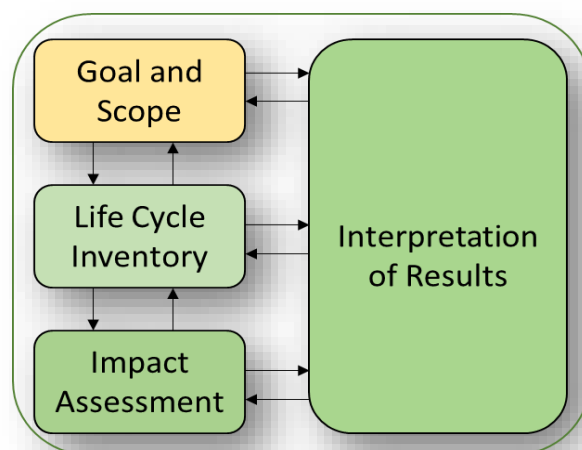


Figure 1: LCA Methodology

➤ Goal & Scope definition

The initial phase of an LCA study involves defining its goal and scope, a crucial step for the determination of choices made in the subsequent phases. Adequate time investment in this phase is recommended to clarify the study's purpose, intended use of results, and inclusion criteria. This upfront clarity streamlines later phases, saving time and resources. It's important to acknowledge that goal and scope may need adjustments as new insights emerge during the study. Unforeseen issues or information gaps may necessitate revisiting and refining the study's goals, reflecting the iterative nature of LCA. According to ISO 14040, the goal of the study should define the intended application and rationale behind conducting the study, the target audience and whether the study results will serve as foundational data for comparative assertions intended for public disclosure. For the definition of the scope of the study the product system, the functions of the product system, the functional unit and reference flow, the system boundaries, the allocation procedures, the environmental impact assessment methodology and types of impacts, and interpretation to be performed. Moreover, data and data quality requirements, assumptions and limitations, critical review considerations should be considered.

➤ Life Cycle Inventory (LCI)

The LCI phase of an LCA consists of two primary components:

1. **Data collection** for each unit process within the defined product system, as established in the goal and scope phase. This entails not only gathering data but also validating it to ensure adherence to quality standards. The quality and relevance of the data utilized in an LCA significantly impact the usefulness and accuracy of the results. This phase typically requires the greatest time investment within the LCA process. As such, meticulous planning and adherence to established data quality requirements from the "Goal and scope" phase are imperative.

The data collection process, based on ISO 14044, typically comprises the following stages: *preparation for data collection, data gathering, validation of collected data, allocation.*

Preparation for data collection typically entail the following procedures: identification of unit processes necessitating data collection, selection of appropriate data sources for gathering information, specification of data documentation requirements and determination of the documentation format for all data collected. **Data collection** for each process within the product system involves gathering information on inputs and outputs, including raw materials, energy use, emissions, discharges, products, co-products, and waste. This often requires collaboration with personnel responsible for various types of data to ensure accurate interpretation and utilization. Internal databases and reports provide additional insights into product performance, usage patterns, market trends, and end-of-life treatment, but their applicability must be assessed and potentially adapted for LCA use. Modeling or estimation may be necessary for certain processes, drawing from theoretical models, similar technologies, technical literature, or expert input. When utilizing external databases or literature, transparency, cost, and usage restrictions must be considered. Continuous documentation of data is recommended to uphold transparency and quality standards. Given the sensitivity of business-related data, secure handling and potential confidentiality agreements are crucial, especially when sharing with partners such as suppliers or customers. During the data collection process, it is essential to **validate the data** to ensure they meet quality standards. Validation methods include performing mass and energy balances to verify the consistency of inputs and outputs according to the laws of conservation, as well as comparing collected data with information from similar processes to assess plausibility. If discrepancies or missing data are identified, additional information may need to be gathered. However, it is common to encounter data gaps that cannot be filled entirely. In such cases, it is crucial to determine how to address these gaps and missing data within the study. During data collection for processes within the product system, it may be necessary to **allocate** inputs and outputs among different products, especially for processes that yield multiple products. Allocation involves dividing raw materials, energy use, and emissions to air, water, and land among the various products. ISO 14040 recommends a stepwise procedure for allocation. Ideally, allocation should be avoided by increasing the system's level of detail. However, if allocation is unavoidable, inputs and outputs should be distributed among products based on their functions or underlying physical relationships. If this is not feasible, allocation can be based on other relationships, such as the economic value of products. Issues may arise when materials are recycled, either directly or multiple times, adding complexity to the allocation process.

2. **Aggregation of data** from individual unit processes **into an inventory result** for the entire product system. This process, as outlined by ISO 14044, includes *relating data to unit processes and the functional unit, aggregating data, and refining system boundaries.* if necessary. The flow chart for the product system serves as a critical tool in this process and should be finalized before aggregation begins. The initial phase of aggregation involves organizing and preparing the collected data for the unit processes within the product system. This begins with **relating the data to each unit process and then normalizing it**

to the defined functional unit. Relating data to unit processes entails establishing the reference flow for each unit process and aligning inputs and outputs with this flow. This may involve allocating inputs and outputs between products as necessary. Normalizing data to the functional unit involves adjusting the inputs and outputs of each unit process to match the defined functional unit. This process is carried out by calculating scaling factors for each unit process based on the flow chart and input-output data, and then scaling each unit process accordingly. This ensures that each unit process contributes appropriately to the production of the functional unit, reflecting its role in the overall system.

Following normalization to the functional unit, the subsequent inventory step involves **aggregating inputs and outputs across all included unit processes.** This entails combining data where substances and environmental impacts are identical. For instance, CO₂ emissions to air from all unit processes are summed to derive the total CO₂ emission for the product system. This consolidated data represents the inventory result for the product system.

➤ Life Cycle Impact Assessment (LCIA)

Life Cycle Impact Assessment (LCIA) aims to assess the potential environmental impacts of a product system based on its inventory results. According to ISO 14040, the impact assessment comprises mandatory and optional elements:

Mandatory elements:

- Selection of impact categories, indicators, and characterization models to quantify environmental impacts.
- Classification of inventory results into selected impact categories, categorizing inputs and outputs based on environmental impact type.
- Characterization involves converting inventory results into category indicator results.

Optional elements:

- Normalization compares category indicator results to reference data, aiding in contextualizing environmental impacts.
- Grouping categorizes impact categories based on relevance, facilitating result interpretation.
- Weighting assigns priorities to different environmental impacts by converting indicator results to a common unit.
- Data quality analysis assesses the quality of impact assessment results by identifying significant contributors, uncertainties, and sensitivities.

In practice, the impact assessment in LCA is typically conducted using a pre-established impact assessment method, such as CML 2002, ECO-indicator 99, Eco-scarcity, ReCiPe, etc. In this case, most of the steps above, such as selection of impact categories and category indicators, classification and models for characterization and weighting are included in the methodology selected.

ReCiPe2016 offers a state-of-the-art methodology for converting life cycle inventories into a concise set of life cycle impact scores at both midpoint and endpoint levels. It includes three endpoint categories (human health, ecosystem quality, and resource scarcity) and 18 midpoint categories. The focus is on providing characterization factors that are globally representative, aligning with the international scope of many product life cycles. Midpoint indicators address specific environmental issues like climate change or acidification, while endpoint indicators reflect impacts on broader categories such as human health, biodiversity, and resource scarcity. Converting midpoints into endpoints facilitates result interpretation, but each level of aggregation introduces more uncertainty into the findings. Figure 2 illustrates the connection between

environmental mechanisms, represented by the 18 midpoint impact categories, and the three areas of protection, known as endpoints, as outlined in ReCiPe2016 [1].

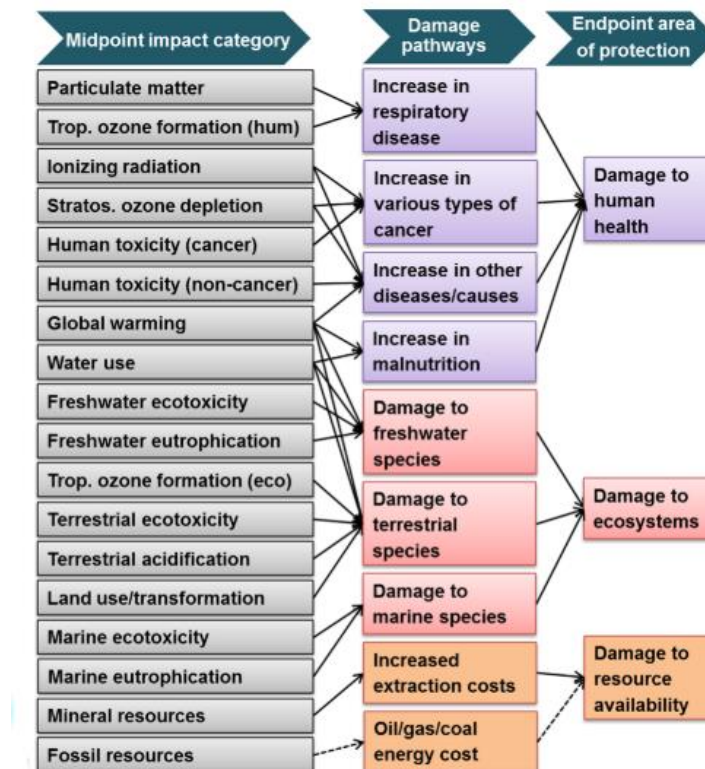


Figure 2: ReCiPe 2016 – overview of impact categories³.

➤ Interpretation of results

Interpretation is a crucial aspect of the LCA process, aimed at deriving conclusions and recommendations aligned with the study's defined goal and scope. It involves integrating and analyzing results from both the inventory (LCI) and environmental impact assessment (LCIA) phases to provide a comprehensive and unbiased overview. It's important to note that interpretation occurs iteratively alongside other phases of the LCA, with each intermediate result being interpreted as part of the overall process. The interpretation phase of an LCA consists of three main elements as per ISO 14040:

- Identification of significant issues based on LCI and LCIA results.
- Evaluation of results, including checks for completeness, sensitivity, consistency, and consideration of uncertainty and data quality analysis findings.
- Drawing conclusions, outlining limitations, and providing recommendations.

In practice, each result from different parts of the study is interpreted individually:

For Inventory:

- Examination of data used for included unit processes.
- Assessment of system boundaries, including decisions on inclusions/exclusions of processes and consequences of cut-offs.
- Analysis of inventory results to identify contributions to overall results and potential areas for improvement.

For Impact Assessment:

- Evaluation of classification and characterization, identifying significant flows and parts of the system contributing to impact assessment results.

- Consideration of weighting results, if applicable, to determine contributions of impact categories and associated flows/processes.
- Significant issues are identified for each intermediate result, with evaluations conducted separately for completeness, sensitivity, and consistency before being combined into an overall assessment for the entire study [2].

2.2 Life Cycle Cost Analysis & Cost-Benefit Analysis

The foundation of the Life Cycle Cost (LCC) methodology dates back to the 1970s, initially devised as a means to calculate the total costs incurred throughout the life cycle of products. Over time, it has become a valuable tool in strategic business and policy decision-making. Unlike Life Cycle Assessment (LCA), LCC lacks a universal standard outlining its application. LCC aims to evaluate not just the procurement costs but also the operational, maintenance, and disposal expenses, allowing decision-makers to enhance the economic performance across the system's life cycle. Additionally, LCC studies may encompass the costs of externalities, such as environmental impacts attributable to the system or product, often guided by the "polluter pays" principle.

Considering the significance of LCA and LCC methodologies, a notable challenge for companies in adopting Life Cycle Assessment (LCA) is comprehending the implications of its findings on their economic metrics. Consequently, integrating LCA with Life Cycle Costing (LCC) appears advantageous. While LCA relies on a comprehensive dataset derived from mass and energy balances identified during the Life Cycle Inventory (LCI) phase, LCC necessitates monetary data concerning financial resources, including expenditures and revenues. LCC is usually applied for the comparison of products, processes, or projects, utilizing economic aspects to highlight those that excel in specific environmental-economic criteria. Variations in cost categories, including direct and indirect costs, internal and external costs, and operational and non-operational costs, are evident across studies.

Various methodologies have been identified for conducting LCC. While there is a consensus on using capital expenditure (CAPEX) and operating expenditure (OPEX) to express results in LCC studies, there remains ambiguity regarding data compilation and handling uncertainties in cost calculations over different time frames. Unlike LCA, there is no globally accepted standard guiding the organization of LCC studies. Nevertheless, most studies express LCC results as the sum of costs per functional unit, similar to LCA, where the functional unit serves as a parameter [3].

While various approaches and practical applications of Life Cycle Costing (LCC) tools exist, the underlying economic methodology at the heart of LCC calculations remains consistent.

LCC costs can be computed using the general formula:

$$LCC = \sum CAPEX + \sum OPEX$$

The analysis of CaPex and OpEx to the various cost categories is presented in Tables 2 & 3.

Direct costs	Indirect costs
Equipment – purchase, delivery	Engineering and supervision
Equipment – installation	Construction expenses
Instrumentation & Controls (installed)	Legal expenses
Piping (installed)	Contractor's fee
Electrical systems (installed)	Contingency
Buildings (including services)	
Yard improvements	
Service facilities (installed)	

Table 2: CapEx analysis.

Direct costs	Indirect costs
Raw materials	Taxes
Labor	Insurance
Utilities	Rent
Maintenance and repairs	Administration

Table 3: OpEx analysis.

Cost-Benefit Analysis (CBA) is crucial in decision-making, especially in economics, public policy, and project management. It provides a systematic framework for evaluating projects, policies, or investments by comparing costs to expected benefits. CBA helps guide decisions in areas such as public infrastructure, environmental regulations, and healthcare. Its core principle is rational decision-making to maximize societal welfare and allocate resources efficiently. By evaluating both tangible costs and intangible benefits, CBA determines whether the projected benefits justify the investment. It offers a structured method for assessing options, prioritizing resources, and ensuring transparency and accountability in public policy. CBA addresses complex societal challenges and helps select economically and socially beneficial strategies.

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The CBA process involves several key steps:

1. Cost and Revenue Identification: Identifying all relevant costs and revenues associated with the project or policy.
2. Benefits Categorization: Recognizing and categorizing benefits into economic, environmental, and social categories.
3. Time Adjustment: Adjusting costs, revenues, and benefits to their present values using an appropriate discount rate.
4. Benefit to Cost Ratio (BCR) Calculation: Dividing the total present value of benefits by the total present value of costs. A BCR over 1 indicates economic favorability.
5. Sensitivity Analysis: Assessing how variations in key parameters influence results.
6. Risk Assessment: Evaluating the impact of risk factors on the project's outcome using probabilistic modeling and scenario analysis.
7. Final Evaluation: Making an informed decision based on BCR and sensitivity analysis. A BCR greater than 1 indicates economic viability; less than 1 suggests it may not be cost-effective [4].

A comprehensive CBA will be conducted in the upcoming year's activities and detailed in the next deliverable, aimed at thoroughly evaluating the effectiveness and impact of the CSA practices.

2.3 Social Life Cycle Assessment

2.3.1 Overview of social LCA

In our contemporary society, a growing number of consumers worldwide are increasingly concerned about the various impacts that are created from the products they purchase; not only towards the environment, but also towards the people who create them. Products such as those that are created by BEATLES UCs demand not only physical resources, but also human resources, involving for example human labor and work time. Consequently, the produced products from the BEATLES UCs possess relevant societal production footprints, which reflect the impact that the products have on the people involved in their production. Nowadays, there is a growing demand for more transparent production chains, where consumers will be able to evaluate the products also taking into account their production footprints; both towards the available resources and to fellow human beings. For the first one, as already mentioned above, the traditional Life Cycle Assessment (LCA) takes into account the environmental impacts of the product, from raw materials to use and up to their disposal; while for the latter one, there is an increasing trend among various companies and policy actors to expand the concept of the traditional LCA approach and include the various social aspects that arise from the whole lifetime of a product, in order to have a more complete sustainability evaluation. As a result, the Social Life Cycle Assessment (s-LCA) emerged, as a holistic method to quantify and analyze the potential positive or negative effects of a product throughout its whole life cycle from a social perspective [5]. This method has been applied in each of the 5 BEATLES UCs to analyze the social production footprints for each of the 5 produced products and its results are presented for each UC separately in section 3.

Similar with the traditional LCA, the s-LCA complies with the ISO 14040 standard and consists of the four major phases presented in section 2.1.2 (see figure 2) [5]. Briefly:

- Goal and scope definition
 - Definition of the objectives and goals of the study, including the specific social aspects or impacts to be assessed.
 - Determination of the boundaries, reference flows, functional units and scope of the assessment.
- Life Cycle Inventory (LCI)
 - Collection of data about the social inputs and outputs.
 - Identification and quantification of the various social indicators and of the required data for the assessment.
- Life Cycle Impact Assessment (LCIA)
 - Analysis of the data to assess the potential social impacts associated with the product or production process.
 - Evaluate the potential impacts on the various social categories.
- Interpretation of results
 - Interpretation of the results of the assessment and characterization of the social performance of the product or production process.
 - Comparison of the findings with established benchmarks or reference values, when available.

- The s-LCA is a relatively new method, meaning that fewer relevant data sources are available, compared with the traditional LCA. Nevertheless, this research field is emerging and highly interesting, as it can reveal not only the social risks in product life cycles, but also potential positive social impacts in them that are not apparent. However, a widely accepted comprehensive database about the social impacts of products over their life cycle does not exist yet. This is mostly because of the more demanding type of the data, as most of the time is of qualitative nature and therefore often inherently subjective and difficult to access, organize and evaluate. As a result, it requires more stringent transparency. One of the first global databases created for s-LCA is the Product Social Impact Life Cycle Assessment database (PSILCA). For the needs of the s-LCA of the BEATLES project, the social impacts were evaluated according to the SOCA database (Version 2). SOCA 2 is an add-on for Ecoinvent LCI databases developed by GreenDelta, which provides information for Social LCA. Based on the PSILCA v.3 database, the SOCA add-on covers social impacts on workers, local communities, entire societies, and value chain actors. It contains more than 70 social indicators related to various categories, including Health & Safety aspects, Fair Salary, Child & Forced Labor, Migration, Corruption, Fair Competition etc [6]. The input information is provided as risk-assessed indicators that are modeled as elementary output flows for every process in the Ecoinvent database. The output information is calculated as social risks for each indicator, complemented by documentary information, like raw values, data quality, sources, etc., for every data point. SOCA 2 combines Environmental LCA, Social LCA and LCC, enabling to perform full Life Cycle Sustainability Assessments [7]. The overall methodology is presented in the following section 2.3.2.

2.3.2 Social LCA Methodology

The PSILCA 3 database, which SOCA 2 is based on, employs a multi-regional input/output system from the Eora 2019 database, in order to provide insights into global supply chains on an industrial sector basis. This features data for 189 individual countries and 14838 total sectors. The latest available year for the Eora 2019 database is 2015, while for most social indicators used in PSILCA 3, the reference year is 2017⁴. The various social indicators, which the PSILCA 3 database uses, are selected based on the studies that formed the “Guidelines for social life cycle assessment of products”, “The Methodological Sheets for Subcategories in Social Life Cycle Assessment (S-LCA)” (2013) and “LCA of an Ecolabeled Notebook - Consideration of Social and Environmental Impacts Along the Entire Life Cycle” (Ciroth and Franze, 2011). They are totally 69 indicators that are organized in 4 categories, namely “Workers”, “Local Community”, “Society” and “Value Chain Actors”. There are various commercially available data sources for these indicators, mainly from statistical agencies, for example International Labor Organisation (ILO & ILOStat), World Bank, World Health Organisation (WHO), United Nations (UN) etc [6].

The value of each indicator is used to assess its risk level, which will be used as the scale characterization factor of the indicator in the final assessment. Typically, 6 different risk levels are used, depending on the derived values (no risk, very low risk, low risk, medium risk, high risk and very high risk). The relationships between the risk levels and the values of the indicators are based on international conventions & standards, labor laws, expert opinions, but also own experience and evaluation. Apparently though, this risk assessment is inevitably subjective to some extend and depends on geopolitical, cultural and even individual evaluations in some cases. More details about these relationships can be found in the user’s manual of the PSILCA 3 database for each indicator [5]. The 62 indicators selected for the BEATLES project, based on PSILCA 3 database, and their respective data sources are presented briefly in the following Table 4. They are measured in different units, such as numerical values, percentages, or even qualitative scales. The indicators were assessed according to either their relevant data sources shown in Table 4, or directly from data provided by the BEATLES UCs, using a relevant questionnaire (see Appendix). More details

about each indicator and the data used for its evaluation are provided for each UCs on below section 3 for each UC separately.

Since SOCA 2 indicators were designed to create a universal assessment method, not all of the indicators are fully relevant with agriculture, crop and farming systems that BEATLES investigate. Instead, the main focus of the analysis will be on 9 indicators that are more relevant with agriculture and the BEATLES UCs and are in accordance with the European CAP context indicators of the Common Monitoring and Evaluation Framework (CMEF) (marked in bold in Table 4) [6].

Category	Indicator	Data source
Worker s	Children in employment, total	World Bank
	Frequency of forced labor	Global Slavery Index
	Good produced by forced labor	US Department of Labor
	Trafficking in persons	2018 Trafficking in Persons report
	Living wage, per month	WageIndicator & TradingEconomics
	Minimum wage, per month	WageIndicator & Country DataBases
	Sector average wage, per month	ILOStat
	Hours of work per employee, per week	ILOStat
	Women in the sectoral labor force	ILOStat
	Men in the sectoral labor force	ILOStat
	Gender wage gap	ILOStat
	Accident rate at workplace, non-fatal	ILOStat
	Accident rate at workplace, fatal	ILOStat
	DALYs due to indoor and outdoor air and water pollution	WHO & Worldometer
	Presence of sufficient safety measures	US Occupational Safety and Health Administration
	Workers affected by natural disasters	International Disaster Database EM-DAT & Worldometer
	Social security expenditures	ILOStat
	Evidence of violations of laws and employment regulations	US Department of Labor
	Trade union density	ILOStat
	Right of Association	ICTWSS
Value Chain Actors	Right of Collective bargaining	ICTWSS
	Right to Strike	ICTWSS
	Presence of anti-competitive behavior or violation of anti-trust and monopoly legislation	US Federal Trade Commission & US Department of Labor
	Public sector corruption	Transparency International
	Active involvement of enterprises in corruption and bribery	OECD Foreign Bribery Report (PSILCA 3 user's manual)
Society	Membership for social responsibility along the supply chain	UN Global Impact & ILOStat
	Global Peace Index (Risk of Conflicts)	The Institute for Economics & Peace
	Contribution of the sector to economic development	UN Statistics Division
	Public expenditure on education	UNESCO Institute for Statistics
	Adult illiteracy rate (15+ years), male	World Bank
	Adult illiteracy rate (15+ years), female	World Bank
	Adult illiteracy rate (15+ years), total	World Bank
	Youth illiteracy rate, male	World Bank
	Youth illiteracy rate, female	World Bank
	Youth illiteracy rate, total	World Bank
	Health expenditure, total	World Bank
	Health expenditure, public	World Bank
	Health expenditure, out-of-pocket	World Bank
	Health expenditure, external resources	World Bank
	Life expectancy at birth	World Bank
Local Commu nity	Violations of mandatory health and safety standards	US Consumer Product Safety Commission & ILOStat
	Level of industrial water use (Total Withdrawal)	AquaStat
	Level of industrial water use (Renewable resources)	AquaStat
	Extraction of materials per population (Fossil fuels)	MaterialFlows & Worldometer
	Extraction of materials per population (Ores)	MaterialFlows & Worldometer
	Extraction of materials per population (Minerals)	MaterialFlows & Worldometer
	Extraction of materials per population (Biomass)	MaterialFlows & Worldometer

Extraction of materials per area (Biomass)	MaterialFlows & Worlddata
Certified Environmental Management Systems	ISO Survey of Management System Standard Certifications & ILOStat
Presence of indigenous population	Wikipedia
Indigenous Rights Protection Index	ILOStat & OHCR & UN
Pollution level of the country	Numbeo
Drinking water coverage (urban, rural, total)	WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene
Sanitation coverage (urban, rural, total)	WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene
Unemployment rate	ILOStat
International migrant workers in the sector	World Population Review & ILOStat
International migrant stock	World Bank
Net migration rate	World FactBook
Immigration rate	OECD.Stat & Worldometer
Emigration rate	OECD.Stat & Worldometer
Asylum seekers rate	OECD.Stat & Worldometer

Table 4: S-LCA indicators and their respective data sources for the Use Cases of the BEATLES project

Following the risk assessment, the indicators are assigned their activity variables. Currently, the activity variable used is the worker hours, defined as “the time workers spend to produce a certain amount of product in the given process or sector” and relate to 1 USD of process output. These are calculated as follows⁴:

$$\text{Worker hours} = \frac{\text{Unit Labour Costs}}{\text{Mean hourly labour costs per employee}} \quad (1)$$

Where:

$$\text{Unit Labour Costs} = \frac{\text{Compensation for employees (Country-specific, sector and year)}}{\text{Gross Output (Country-specific, sector and year)}} \quad (2)$$

The “Compensation of employees” is defined as “the total remuneration, in cash or in kind, payable by an enterprise to an employee in return for work done by the latter during the accounting period” and consists of wages, salaries and any social insurance contributions payable by the employer (net and gross salaries and related expenditures). Similarly, the “Gross Output” is defined as “the intermediate consumption plus value added of each group of producing unit (industry)” and calculated from the Eora 2019 database, while the “Mean nominal hourly labor cost per employee” is derived from ILOStat. Although the “Worker hours” is a variable that by definition is related to the indicators of the “Workers” category, currently it is applied to the indicators of the other categories as well, as other more relevant activity variables for them are still being evaluated⁴.

For the BEATLES project, the “Worker hours” variable was calculated for each Use Case Scenario separately and assigned to all the indicators, using information from the LCC analysis, whereas the production flows were the same as the ones used in the LCA analysis. Regarding the social indicators, a relevant questionnaire was sent to each UC and the relevant data were used where applicable, otherwise it was taken from the data sources mentioned in Table 4. The final impact assessment was conducted using the “Social Impacts Weighting Method” of the PSILCA 3 database, which applies exponential relations between the impact factors and the associated risk levels of the indicators. The resulting impacts from the indicators were adjusted and measured in Disability-Adjusted Life Years (DALYs), which measure the overall disease burden and are expressed as the number of years lost due to ill-health, disability, or premature death⁴.

It is important to note here that the s-LCA is an emerging method and thus constantly changing and evolving. Currently, most of the data sources of SOCA 2 that are mentioned in table 4 contain data on national level and/or sectoral level; however, many of them are even on global scale and/or containing data of qualitative origin. All the aforementioned limitations make the interpretation

of the results for the needs of defined projects like BEATLES quite challenging. Additionally, due to the many differences between the various Use Cases of the BEATLES project, regarding responses in the questionnaires, financial data, production flows, final products and even geographical locations, it is neither appropriate nor fair to compare the results between the Use Cases, as the analysis on a Life Cycle basis involves many hidden steps that depend on many factors, such as industry sectors, geographical locations etc. These are current limitations of the methodology; nevertheless, the s-LCA analyses can be used to reveal potential social benefits and drawbacks that will arise when comparing the current baselines of each Use Case with a proposed future application of a CSA practice for that particular UC, since these will have only minor changes between them, mostly related with their production flow charts and their applied activity variables.

2.4 Theory of Change (ToC)

2.4.1 Overview of ToC

Theory of Change (ToC) is a method that describes the way in which an intervention, or a group of interventions, leads to a desired change. It describes how the various activities are expected to produce certain outcomes that will contribute to achieving the final intended change. A ToC must be driven by sound analysis, consultation with key stakeholders and learning on what works and what does not in diverse contexts drawn from experience. Additionally, a ToC can be used in order to determine any assumptions made for the intervention to happen and to identify solutions for various risks and problems that hinder the desired progress [8]. A ToC methodology is typically used for planning participation, management and evaluation, in order to promote a social change; a process whereby individuals and communities adjust or abandon customs and associated leading ideas, values and purposes to act differently in response to random (unique) or systemic factors. A ToC method can be developed for any level of intervention, from a single event up to an organization [9].

A ToC methodology can be represented by a diagram that depicts the relationships between the chosen strategies and the expected outcomes, usually as a series of boxes from inputs to outputs, outcomes and impacts (e.g. see Figure 3). Sometimes multiple boxes are shown for each stage and the relevant boxes linked to show how particular activities lead to particular outputs and how particular outputs lead to particular outcomes, always combined with the assumptions and risks made in each stage.



Figure 3: Basic Theory of Change methodology diagram

There are four steps involved in the development of a ToC methodology. Briefly:

- Focus on the high-level change
 - Define the goals and objectives of the study, identify the problem that ToC seeks to address, its causes and consequences.
 - Search for opportunities (e.g. synergies with other initiatives, strengthening of existing resources).
- Develop the way to go to the desired situation from the current one

- How this change will come about.
- How the intervention will trigger this change.
- Define assumptions underpinning the ToC and possible risks
- Focus on things that are expected that will affect the intervention outcomes.
- Analysis of the risks involved.
- Identify partners & key actors
- Revisit each result, including the related risks and assumptions.

A theory of change implies a shift in focus to contribution rather than attribution, to acknowledge the role and inputs of partners and other actors both in achieving outcomes and in providing evidence for those outcomes. Concisely, a ToC explains how and why a sequence of logically linked events should lead to a desired outcome. This is achieved by articulating assumptions and the beliefs and hypotheses they rely on. It shows how short-, medium-, and/or long-term change happens in a specific context; and stipulating how early and intermediate outcomes contribute towards the long-term change, using indicators that describe how much of, for whom, and when each outcome is to be realized. The theory of change and the impact pathways have to be harmonized so that they contribute to the project targets. With an appropriate theory of change defined, indicators and baselines are needed so that the assumptions underlying them can be continuously tested and project's contributions checked for alignment and plausibility.

2.4.2 ToC Methodology

The main objective of the BEATLES project is to propose innovative, systemic solutions, with regard to business strategies and policy recommendations and tools, in order to encourage long-term and large-scale transitions to sustainable, productive, and climate-smart agri-food systems. By creating a ToC for the Climate Smart Agricultural (CSA) Practices, organizations and stakeholders can better plan, implement, and assess the effectiveness of CSA interventions in addressing climate change challenges and promoting sustainable agriculture. This framework will also help in fostering transparency, accountability, and evidence-based decision-making in CSA initiatives.

The BEATLES consortium aims to engage various value chain actors and relevant policy actors, who possess extensive knowledge and experience with all the key components of the project and are able to provide experienced trainers and high-quality education material (Figure 4). Additionally, a wide range of stakeholder networks from global multiplier organizations supports BEATLES project by having an active role in the design and implementation of behavioral and experimental research, co-creation and dissemination activities (e.g. IFOAM and IFRI Europe through Naturland, BEUC and ANEC through ZPS), while on the other hand participation of non-research stakeholders (e.g. farmers, advisors, processors, retailers, investors, consumers, policy makers) in the early stages of the project is critical.

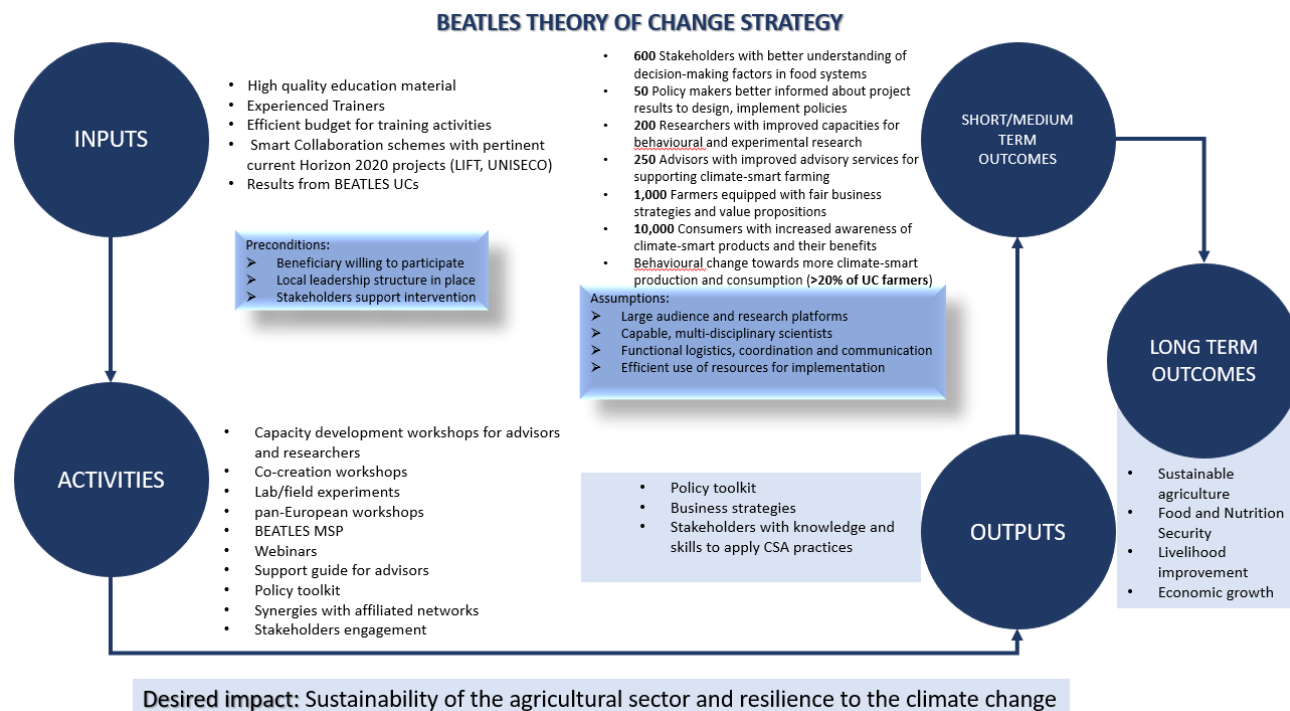


Figure 4: Theory of Change methodology of the BEATLES project

High quality education material and scientific experienced trainers are going to be the basic inputs in order to achieve the expected results. Researchers will then use existing evidence to guide the development and evaluation of the BEATLES interventions. BEATLES ToC plan is twofold: a) to provide a set of business strategies establishing roadmaps for a fair shift towards Climate Smart Agriculture practices, and b) to suggest as a series of policy recommendations and tools that will foster behaviorally informed policy design and implementation. More specifically regarding policy, the perceptions of fairness are key to commit the actors to change and to achieve large-scale and long-term transitions towards climate-smart food systems. A critical component of the ToC is the active participation of multiple value chain actors, at various levels of society (public, political, professional) that establish a mutual understanding of the value chain and unravel benefits and bottlenecks that define the pathways to the desired change. Evaluation criteria include traditional output-focused criteria, as well as progress towards outcomes, partnerships and learning. The goal is to increase the individual stakeholders' awareness, knowledge, skills, employability and confidence to implement the suggested solutions.

To achieve the ToC plan, a series of activities are being conducted (e.g. workshops, trainings, e-learning modules etc.) and relevant questionnaires created to evaluate the outcomes of these activities. The development of the questionnaires has been conducted using the Typeform online platform. This platform provides the necessary tools for the distribution of the questionnaire, collection of the responses, as well as quantitative and qualitative analysis. Currently, relevant questionnaires have been communicated with the BEATLES partners and responses collected regarding 4 actions (Consumer survey (WP2), Farmer questionnaires (WP4), Co-creation workshops and Webinar), while an additional questionnaire is prepared for the upcoming multi-actor workshop. The questionnaire regarding the consumer survey has been incorporated within the main one about the survey, while the other three were prepared as supplementary questionnaires in Typeform online platform and distributed through URL links and QR codes (Table 3). The results from the analyses of the responses received are presented in section 3.6.

Action	URL Link	QR Code	Responses
Consumer survey (WP2)	Questions incorporated in main survey		3606
Farmer questionnaires (WP4)	https://form.typeform.com/to/BUQGK5C4		8
Co-creation workshop	https://form.typeform.com/to/JvzbAyeP		15
Webinar	https://form.typeform.com/to/Vl50nEG8		33

Table 5: Online sources of the ToC Questionnaires of the BEATLES project and their current status

2.5 Selection of CSA practices

The target for WP3 is the sustainability assessment of at least 25 climate smart agricultural (CSA) practices. For this reason, 5 CSA practices per UC have been chosen which will be examined in other WPs as well (WP2, WP4, WP5). The specific practices were drawn from the practices outlined in D1.2. A review of the literature on the sustainability impact of CSA practices has been carried out to furnish pertinent information for the selection of these practices.

The selection of the CSA practices was based on the following criteria:

- CSAs with potential environmental benefits
- CSAs that are easy to adopt and already widely used and CSAs more difficult to adopt and not widely used
- CSAs whose application is of interest for a specific UC

The selected CSA practices are listed in Table 6.

UC1 (Lithuania – wheat cultivation)	UC2 (Spain – apple orchard)	UC3 (Germany – dairy farm)	UC4 (Denmark – pig farm)	UC5 (The Netherlands – potato & onion cultivation)
Intercropping	Cover crops	Organic/Naturland: 40% forage, 10% maize, 10% grains for feed, 40% clover grass – reduced number of animals, and other parameters according to Naturland standards	Frequent discharge of slurry	Sustainable irrigation systems [including energy consumption of the systems (diesel, electricity, green electricity)]
No-tillage system	Floral bands	Feed conversion to 100% forage	Acidification of slurry	Green energy (ratio of green/grey energy)
(Extensive) wetland management	Grazing	Regional protein source	Use of biogas	Precision fertilization and soil management

Alternative green energy	Organic farming	Breeding for longevity	Green protein for feed	Biodiversity measures (farm level)
Precision farming (variable rate fertilisation or irrigation)	Renewable energy (e.g. solar energy)	Agrophotovoltaic systems	Technologies for ventilation	Crop protection (all IPM measures, total impact)

Table 6: Selected CSA practices per UC

3. Application of methodology in BEATLES project

The first two stages (Goal and Scope definition and Life Cycle Inventory) of the methodology utilized for the environmental, economic, and social assessment of the examined systems were uniform across the three evaluations and are described in the subsections 3.x.1 and 3.x.2. The description of each type of assessment is provided separately in the next subsections (3.x.3-3.x.6).

3.1 Use Case Pilot #1: Wheat farming, Lithuania

3.1.1 Goal & Scope definition – Wheat farming, Lithuania

The **goal** of the assessments undertaken (LCA, LCC and s-LCA) is to conduct an environmental, economic, and social evaluation of the Lithuanian UC baseline scenario. This scenario represents a conventional farm that does not include any of the CSA practices that will be studied in next year activities. This evaluation will serve as a benchmark for the comparison with the alternative scenarios that incorporate the CSA practices.

For the definition of the **scope** of the study, after thorough communication with the Lithuanian UC leader, process flow diagram depicting the baseline scenario (product system) has been developed. The studied UC is briefly outlined, accompanied by flowchart illustrating the process (Figure 5), and supplemented with data collected from distributed questionnaires.

Product system:

The product system is a wheat farm that does not apply any of the CSA practices. This farm has been studied in this year's activities and will be compared with scenarios that include CSA practices in next year's activities. The main processes along with all the relative flows are presented in Figure 5.

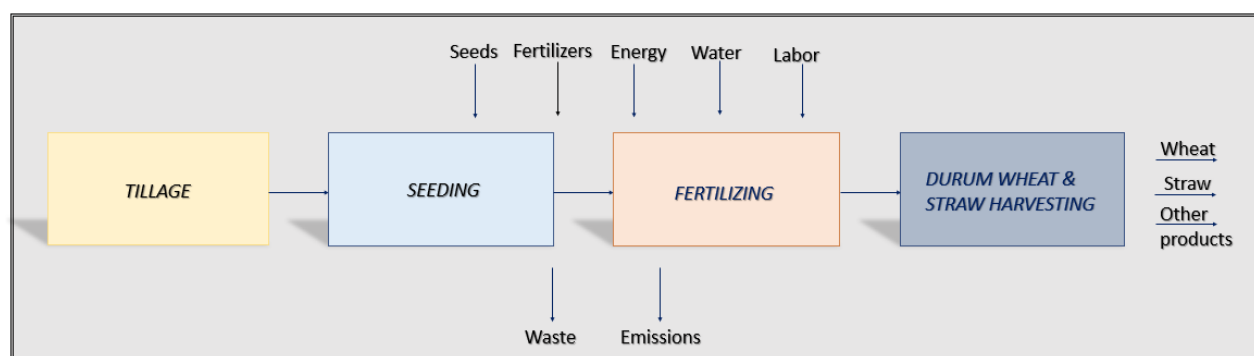


Figure 5: Flowchart of the Lithuanian UC baseline scenario.

Functions of the product system: The main processes involved in wheat cultivation are the tillage, the seeding, the fertilizing and the harvesting of durum wheat and straw. The sustainability assessment will consider the overall flows of the entire product system rather than individually for each process.

Functional unit: 1 ha of cultivated land.

System boundaries: A cradle-to-gate approach has been selected for the sustainability evaluation of the product system, as the effect of the CSA practices that will be studied in the next year's activities is depicted on these stages. More specifically, the boundaries of the system encompass all the stages from the land preparation till the harvesting of the final product.

Allocation procedures: Since there are no multiple products involved, no allocation is needed.

Environmental impact assessment methodology and types of impacts, and interpretation to be performed: ReCiPe 2016 (H, hierarchist) was used in order to convert the LCI data into a set of environmental impact scores using characterization factors. Detailed description of the method is provided in subsection 2.1.2. The aim of the study is the comparison of different scenarios; thus, ReCiPe 2016 was selected as the most appropriate, because it offers several advantages. More specifically, ReCiPe 2016 is designed to be a versatile and comprehensive methodology that covers a wide range of impact categories and life cycle stages. It provides a standardized framework for assessing environmental impacts across different stages of a product's life cycle, such as raw material extraction or production. Consistency in methodology application and interpretation across different scenarios or studies is also ensured in this methodology. This consistency is crucial when conducting comparisons because it minimizes variability due to methodological choices and enhances the reliability of the results. Moreover ReCiPe 2016 is based on transparent and documented procedures, making it easier for researchers and stakeholders to understand and reproduce the results. This transparency is essential for ensuring the credibility of the LCA findings, especially when comparing scenarios with potentially different boundary conditions or assumptions. Last but not least, the methodology includes a broad set of impact categories beyond just carbon footprint, such as acidification potential, eutrophication potential, and resource depletion. This allows for a more holistic assessment of environmental impacts, which is beneficial when comparing scenarios that may have different environmental trade-offs across various impact categories.

Data requirements: To conduct the LCA analysis, data were gathered through the distribution of questionnaires to relevant stakeholders, supplemented by data from verified databases such as Ecoinvent, Agri-footprint and Agribalyse, which cover the geographical area of the European Union 28 (EU-28). The collected data refer to the last cultivation period (seeding 2022 autumn, yield 2023 summer).

Assumptions/Limitations: The collected data correspond to a farm that is representative of a conventional wheat farm in Lithuania. More specifically, the product system is a farm located in the southwestern part of Lithuania, cultivating 3.98 ha predominantly of wheat each year.

3.1.2 Life Cycle Inventory (LCI) – Wheat farming, Lithuania

The next step after defining the goal and scope of the study was the life cycle data inventory, which linked all activities with quantitative data according to the selected functional unit. For the development of the data inventory, appropriate questionnaires in the form of data sheets were prepared and provided to the UC leader for distribution to the relevant stakeholders (farmers, advisors, etc.). Following data collection, validation and aggregation of these data were performed. Where necessary, supplementary data from appropriate databases (Ecoinvent, Agribalyse, Agri-footprint) or literature sources were used for the establishment of the LCI. The LCI inventory is

presented in Table 7, with all flows aggregated using 1 ha of cultivated land per year as the Functional Unit.

Parameter	Unit	Value	Data source	Comment
INPUTS				
Land use (FU)	ha	1	Farmer interview	Functional unit
Raw materials				
Wheat seeds	kg	200	Farmer interview	
Fertilizers				
Chemical fertilizer	kg	200	Farmer interview	NPK 33-3-0 33% N in total fertilizer 3% P in total fertilizer
Nitrogen in fertilizer	kg	66		
Phosphorus in fertilizer	kg	6		
Other chemicals				
Herbicides	L	0.8	Farmer interview	
Energy				
Diesel fuel	L	92	Farmer interview	
Water				
Water from public network	L	200	Farmer interview	
OUTPUTS				
Grains	tonne	5	Farmer interview	Plastic container (size - 5 L)
Packaging (waste)	piece	3	Farmer interview	
Herbicides [Emissions to agricultural soil]	g	617.2	Literature [10]	
Herbicides [Emissions to air]	g	92		

Table 7: Life Cycle Inventory of a conventional wheat farm – Lithuanian UC, baseline scenario. The values are given per ha per year.

The estimation of the initial emission distribution fractions of the applied chemical agents (fungicides, herbicides, insecticides and phytochemicals) was based on emission modelling for pesticides provided in literature [10]. More specifically, the emissions to soil, water and air were estimated based on the percentage of the active compound per case and the appropriate coefficients provided for the category of Pooideae (wheat).

3.1.3 Environmental Life Cycle Impact Assessment (e-LCIA) – Wheat farming, Lithuania

LCA analysis was performed for the baseline scenario based on the data collected from the UC (Table 7), utilizing the SimaPro 9.6 software. For reference, the results of the impact assessment of a relevant scenario with data available in Ecoinvent database for wheat grain production in Germany are also presented in Tables 8 & 9. Due to lack of average data for wheat grain production in Lithuania, data regarding the wheat cultivation in Germany have been used, as these countries present similarities in their climatic conditions due to their relative proximity in Europe.

Impact category	Unit	Baseline wheat farm (BEATLES)	Baseline wheat farm (Ecoinvent)
Global warming	kg CO ₂ eq	3.41E-02	4.61E-01
Stratospheric ozone depletion	kg CFC11 eq	4.62E-07	7.02E-06
Ionizing radiation	kBq Co-60 eq	2.50E-05	1.16E-02
Ozone formation, Human health	kg NO _x eq	2.65E-03	1.54E-03
Fine particulate matter formation	kg PM _{2.5} eq	8.73E-05	9.68E-04
Ozone formation, Terrestrial ecosystems	kg NO _x eq	4.24E-03	1.16E-02
Terrestrial acidification	kg SO ₂ eq	3.07E-04	5.13E-03
Freshwater eutrophication	kg P eq	2.67E-05	1.36E-04
Marine eutrophication	kg N eq	1.64E-06	3.68E-03
Terrestrial ecotoxicity	kg 1,4-DCB	5.63E-03	4.64E+00
Freshwater ecotoxicity	kg 1,4-DCB	1.08E-04	1.95E-02
Marine ecotoxicity	kg 1,4-DCB	1.58E-04	2.83E-02
Human carcinogenic toxicity	kg 1,4-DCB	3.41E-05	6.88E-02
Human non-carcinogenic toxicity	kg 1,4-DCB	1.21E-02	6.52E-01
Land use	m ² a crop eq	4.30E-03	3.47E+00
Mineral resource scarcity	kg Cu eq	3.02E-05	1.16E-02
Fossil resource scarcity	kg oil eq	2.98E-02	8.26E-02
Water consumption	m ³	8.48E-05	3.75E-02

Table 8: Results of impact assessment of the Lithuanian UC baseline scenario (based on data collected by UC leader for a conventional wheat farm) per ha of cultivated land per year – midpoint indicators. Results of a relevant scenario based on data obtained from Ecoinvent database are presented in the final column.

Impact category	Unit	Baseline wheat farm (BEATLES)	Baseline wheat farm (Ecoinvent)
Ecosystems	species.yr	8.68E-10	1.57E-08
Damage to Human health	DALY	1.26E-07	1.19E-06
Resources	USD2013	1.13E-02	3.02E-02

Table 9: Results of impact assessment of the Lithuanian UC baseline scenario based on data collected by UC leader for a conventional wheat farm) per ha of cultivated land per year – endpoint indicators. Results of a relevant scenario based on data obtained from Ecoinvent database are presented in the final column.

Table 8 lists the annual average impacts per ha of cultivated land for the 18 midpoint impact categories under investigation, based on the methodology followed (ReCiPe 2016, H). The UC farm presents lower environmental impact than the scenario of Ecoinvent in many categories, probably due to the different climatic conditions, the different fertilization techniques and the machine utilization. The results of the environmental assessment of this UC scenario will be used in the next year activities as a baseline for comparison with scenarios that include the application of selected CSA practices on farms located in Lithuania.

A detailed percentage distribution of the contribution of each agricultural input in the 18 midpoint impact categories is presented in Table 10. The effect of each input in selected midpoint impact categories is also presented in Figure 6.

Impact category	Unit	Herbicides	Diesel	Plastic Waste (PE, PP, PS, PB)	Emissions (chemical agents)	Fertilizers	Wheat seed production
Global warming	kg CO2 eq	3.38%	21.16%	0.22%	0.00%	75.24%	0.00%
Stratospheric ozone depletion	kg CFC11 eq	0.72%	2.25%	-0.01%	0.00%	97.04%	0.00%
Ionizing radiation	kBq Co-60 eq	18.65%	89.86%	-8.51%	0.00%	0.00%	0.00%
Ozone formation, Human health	kg NOx eq	19.85%	75.87%	3.63%	0.00%	0.64%	0.00%
Fine particulate matter formation	kg PM2.5 eq	0.72%	7.84%	-0.36%	0.00%	91.80%	0.00%
Ozone formation, Terrestrial ecosystems	kg NOx eq	19.96%	75.96%	3.68%	0.00%	0.41%	0.00%
Terrestrial acidification	kg SO2 eq	0.64%	8.03%	-0.33%	0.00%	91.66%	0.00%
Freshwater eutrophication	kg P eq	0.03%	0.52%	0.00%	0.00%	99.46%	0.00%
Marine eutrophication	kg N eq	2.52%	89.40%	-0.02%	0.00%	8.10%	0.00%
Terrestrial ecotoxicity	kg 1,4-DCB	2.26%	28.55%	-0.65%	0.48%	69.36%	0.00%
Freshwater ecotoxicity	kg 1,4-DCB	0.19%	8.28%	-0.01%	0.03%	91.50%	0.00%
Marine ecotoxicity	kg 1,4-DCB	0.34%	17.19%	-0.03%	0.01%	82.49%	0.00%

Table 10: Percentage contribution of each flow in the various midpoint indicators – baseline scenario, Lithuanian UC.

Impact category	Unit	Herbicides	Diesel	Plastic Waste (PE, PP, PS, PB)	Emissions (chemical agents)	Fertilizers	Wheat seed production
Human carcinogenic toxicity	kg 1,4-DCB	1.67%	29.32%	-0.08%	0.00%	69.09%	0.00%
Human non-carcinogenic toxicity	kg 1,4-DCB	0.27%	33.16%	-0.02%	0.00%	66.59%	0.00%
Land use	m ² a crop eq	0.40%	99.46%	0.00%	0.00%	0.00%	0.14%
Mineral resource scarcity	kg Cu eq	6.04%	93.85%	0.11%	0.00%	0.00%	0.00%
Fossil resource scarcity	kg oil eq	1.91%	57.43%	-0.25%	0.00%	40.91%	0.00%
Water consumption	m ³	11.72%	87.84%	0.44%	0.00%	0.00%	0.00%

Table 10: Percentage contribution of each flow in the various midpoint indicators – baseline scenario, Lithuanian UC (continued).

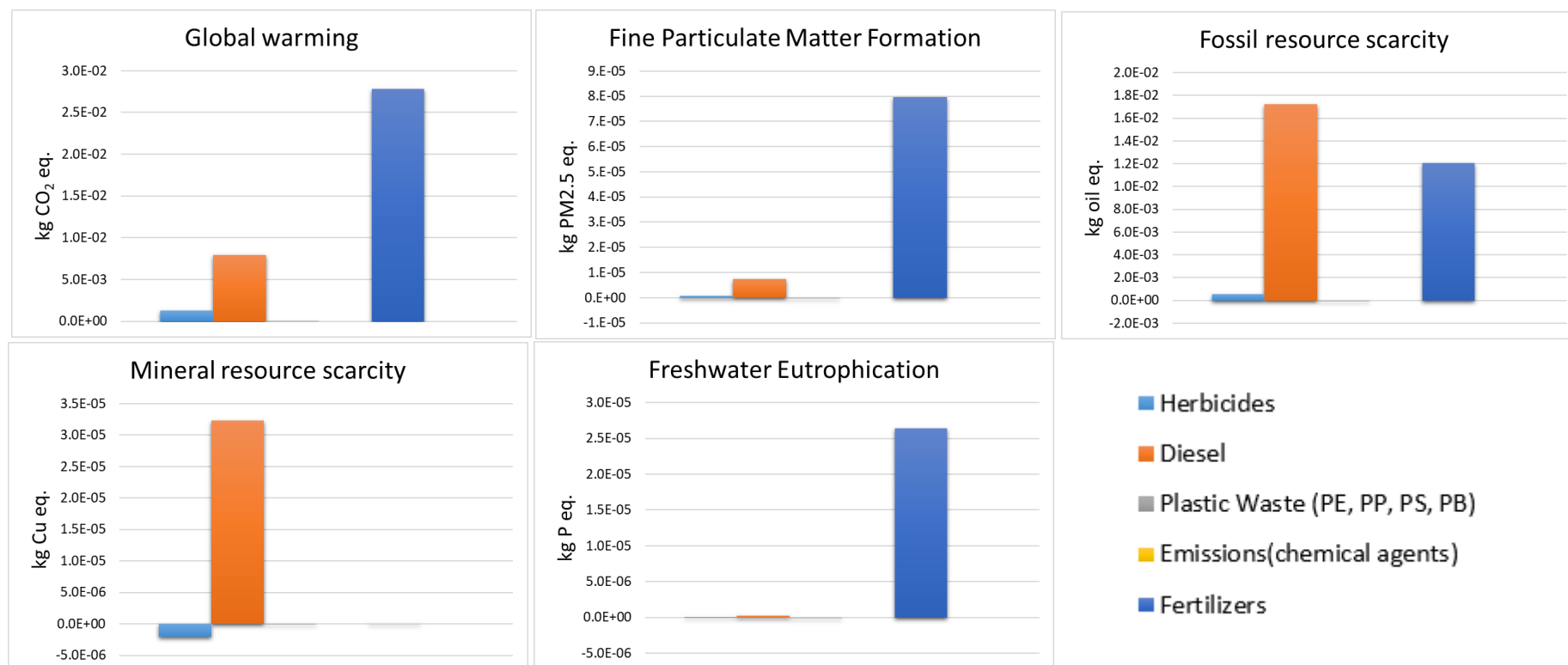


Figure 6: Contributing processes to the midpoint impacts per ha of cultivated land per year for the baseline scenario – Lithuanian UC.

The analysis of each input's contribution to the total environmental impact indicates that the use of synthetic fertilizers and the diesel consumption are the main factors for the environmental burden of this wheat farm. The impact categories that are mainly affected in the current scenario, include the global warming and the fossil resource scarcity. Emissions of greenhouse gases are the main factor for the increase of Earth's temperature, known as global warming. The contribution of fertilizers to the global warming impact is up to 75% and is attributed to the emissions of nitrous oxide resulting from the use of nitrogen fertilizers and the embodied impacts related to producing significant volumes of micronutrient fertilizers. The use of diesel contributes also significantly to the global warming potential, at a percentage of 21%. As anticipated, fossil resource scarcity is primarily linked to the consumption of diesel for agricultural activities, accounting for 57.4% of the impact in this category. The 40.9% of the impact is associated with the use of fossil fuels in energy production during the manufacturing of synthetic fertilizers and pesticides. Fossil resource scarcity refers to the diminishing availability of non-renewable fossil fuel reserves, such as oil, coal, and natural gas, which are essential for energy production and various industrial processes. The application of appropriate CSA practices can be a key approach for the depletion of finite fossil resources. The contribution of fertilizers to freshwater eutrophication is driven by the included phosphorus and the nitrate emissions or the nitrous oxide emissions, respectively. However, this impact is not significant (order 10^{-5}), as the amount of phosphorus in the applied fertilizers is very low.

3.1.4 Interpretation of LCA results – Wheat farming, Lithuania

Diesel use and fertilizer use are the main categories that contribute to the environmental burden of the Lithuanian UC. To address these issues, measures should be implemented to reduce the use of diesel and synthetic fertilizers, as well as to promote the production of energy credits. Energy credits can play a crucial role in decreasing diesel use in farm equipment by incentivizing the adoption of renewable energy sources and more efficient technologies. This scenario will be used as baseline for comparison with scenarios that include the application of selected CSA practices that have increased potential towards this direction.

3.1.5 Life Cycle Cost Analysis (LCC) – Wheat farming, Lithuania

For the calculation of the life cycle costs of a wheat production cycle (Lithuanian UC, baseline scenario), only OpEx was taken into account as any equipment, land, building or other CapEx are considered to have been depreciated and only maintenance costs are taken into account. In Figure 7 are presented the expenditures, along with the revenues including subsidies and sale of wheat grains. Labor costs were not taken into consideration, as the studied farm is a family-run operation, and the profit directly reflects the farmer's revenues. A large percentage of the OpEx corresponds to the direct costs (724.6 €/ha), including the raw materials, fertilizers, herbicides and utilities costs. The indirect costs are calculated up to 212.5 €/ha. The total revenues of the farm, along with the subsidies provided sum up to 1285 €/ha, leading to a sum profit of 348 €/ha.

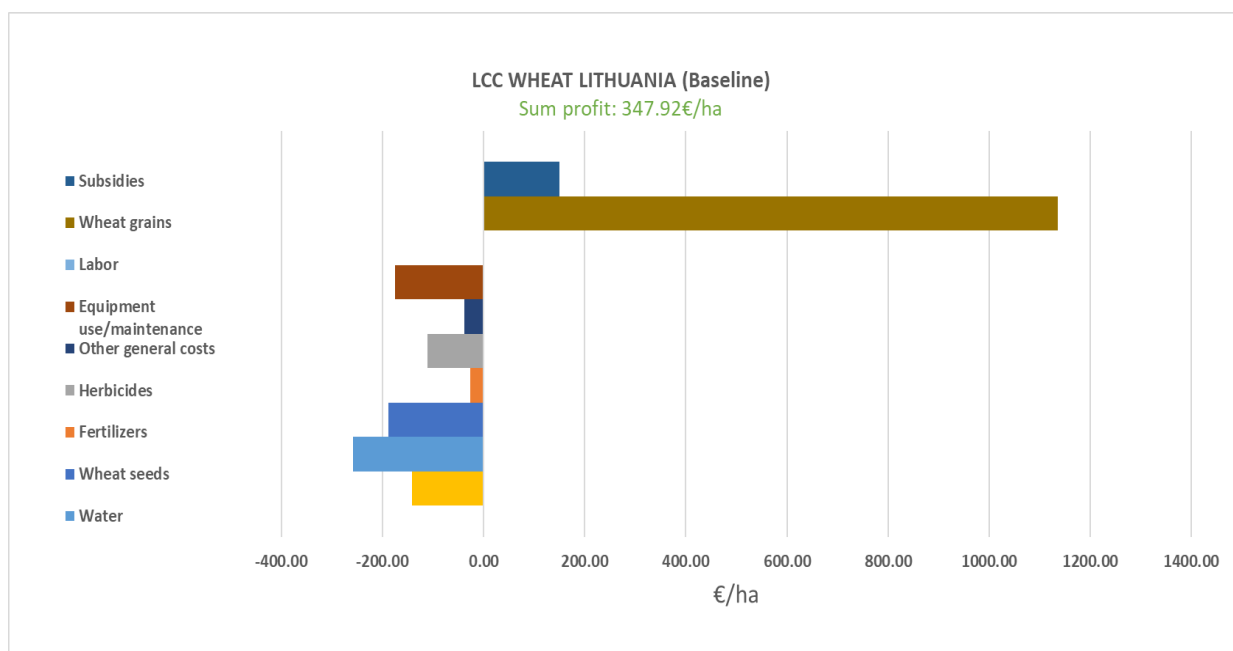


Figure 7: Life Cycle Cost Analysis of the Lithuanian UC, baseline scenario (Positive values correspond to annual revenues, negative values correspond to annual expenses).

3.1.6 Social Life Cycle Impact Assessment (s-LCIA) and interpretation of results – Wheat farming, Lithuania

The production flows and relevant inventory data of the Lithuanian Baseline scenario were taken from the resulting LCIA shown in previous section 3.1.2. Data inputs and calculated results for the social indicators of the Lithuanian Baseline scenario are presented in Table 10. Values in bold were values taken directly from the distributed questionnaire, while values with normal fonts were taken directly from the data sources presented in Table 4. Regarding the “Worker hours” activity variable, data for all the parameters were taken from Eora 2019 and ILOStat databases. The Unit labor cost was calculated based on an annual production of 5 tonnes of wheat grains per hectare and an average annual compensation of 14294.4 € per hectare. The hourly labor costs were calculated assuming 4.5 weeks/month. Using the values from the databases, the activity variable “Worker hours” was calculated as follows: the activity variable was used in every indicator and the respective DALYs were calculated. Note that some indicators give combined results (e.g. the 3 wage indicators have combined output as “Fair Salary” - see Table 11 & Figure 8):

$$\text{Unit Labour Costs} = \frac{14294.4}{5000} = 2.8589 \text{ €}$$

and

$$\text{Worker hours} = \frac{2.8589 \text{ €}}{7.4777 \text{ €/h}} = 0.3823 \text{ h}$$

Indicator	Value	Risk level	Calculated DALYs
Children in employment, male	No Data	No Data	5703.66
Children in employment, female	No Data	No Data	780.59
Children in employment, total	No Data	No Data	778.73
Frequency of forced labor	6.1	Low	3204.57
Good produced by forced labor	No Data	No Data	12.31
Trafficking in persons	1	Very Low	210.07
Living wage, per month	740.9	High	-
Minimum wage, per month	0.8	Low	-
Sector average wage, per month	1.29 & 1.61	Medium	-
Fair Salary	-	-	4561.35
Hours of work per employee, per week	35.4	Medium	515.67
Women in the sectoral labor force	0.93	Very Low	139.50
Men in the sectoral labor force	1.08	Very Low	0.90
Gender wage gap	3.51%	Very Low	442.48
Accident rate at workplace, non-fatal	0	Very Low	12.04

Accident rate at workplace, fatal	0	Very Low	6.01
DALYs due to indoor and outdoor air and water pollution	16.88	Medium	77.09
Presence of sufficient safety measures	Yes	Very Low	305.49
Workers affected by natural disasters	0.1112%	Very Low	48.33
Social security expenditures	12.20%	Medium	4964.61
Evidence of violations of laws & employment regulations	0.1<y<1	Low	520.16
Trade union density	7.4	Very High	5054.06
Right of Association	2	Low	-
Right of Collective bargaining	2	Low	-
Right to Strike	2	Low	-
Association and Bargaining rights	-	-	458.06
Presence of anti-competitive behavior or violation of anti-trust & monopoly legislation	0.0461	Very Low	5129.49
Public sector corruption	61	High	6008.15
Active involvement of enterprises in corruption & bribery	4%	Low	571.13
Membership for social responsibility along supply chain	No	Very High	548.68
Global Peace Index (Risk of Conflicts)	1.67%	Low	591.32
Contribution of the sector to economic development	3.47	Low Opportunity	50.44
Value added (total)	-	-	13.16
Public expenditure on education	6.24	Medium	50.28
Adult illiteracy rate (15+ years), male	0	Very Low	5237.41
Adult illiteracy rate (15+ years), female	0	Very Low	7462.93
Adult illiteracy rate (15+ years), total	0	Very Low	6825.68
Youth illiteracy rate, male	0	Very Low	530.78
Youth illiteracy rate, female	0	Very Low	525.74
Youth illiteracy rate, total	0	Very Low	688.50
Health expenditure, total	7.50%	Medium	-
Health expenditure, public	68.70%	Low	-
Health expenditure, out-of-pocket	28.70%	Medium	-
Health expenditure, external resources	0.60%	Very Low	-
Health expenditure	-	-	2392.95
Life expectancy at birth	74	Low	495.24
Violations of mandatory health and safety standards	20E-7	High	-
Level of industrial water use (Total Withdrawal)	24%	Medium	-
Level of industrial water use (Renewable resources)	0.24%	Very Low	-
Industrial water depletion	-	-	130.71
Extraction of materials per population (Fossil fuels)	0.02	Very Low	0.96
Extraction of materials per population (Ores)	0.00	Very Low	-
Extraction of materials per population (Minerals)	10.09	High	-
Minerals' consumption	-	-	94.31
Extraction of materials per population (Biomass)	8.50	Medium	-
Extraction of materials per area (Biomass)	351.29	Low	-
Biomass consumption	-	-	5541.88
Certified Environmental Management Systems	No	Very High	1986.03
Presence of indigenous population	No	No risk	-
Indigenous Rights Protection Index	3	Medium	-
Indigenous rights	-	-	133.93
Pollution level of the country	26.9	Low	943.03
Drinking water coverage (urban, rural, total)	93.78% & 99.32%	Low & Very Low	8163.93
Sanitation coverage (urban, rural, total)	90.53% & 97.51%	Low & Very Low	3957.15
Unemployment rate	6	Low	450.19
International migrant workers in the sector	0	No Risk	3227.46
International migrant stock	4.7	Low	63.85
Net migration rate	-4.3	Low	0.99
Immigration rate	0.00784	Low	-
Emigration rate	0.00236	Low	-
Asylum seekers rate	1.63E-05	Very Low	-
Migration flows	-	-	414.90
GHG Footprints	No Data	No Data	2832.19
Embodied agricultural area footprints	No Data	No Data	95.27
Embodied biodiversity footprints	No Data	No Data	3675.44
Embodied forest area footprints	No Data	No Data	1.52
Embodied water footprints	No Data	No Data	326.54

Table 11: S-LCA Data for the Lithuanian Baseline scenario of the BEATLES project: Indicator values, associated risk levels and calculated DALYs for 1 year of production (Values in **bold** are data taken from the distributed questionnaire)

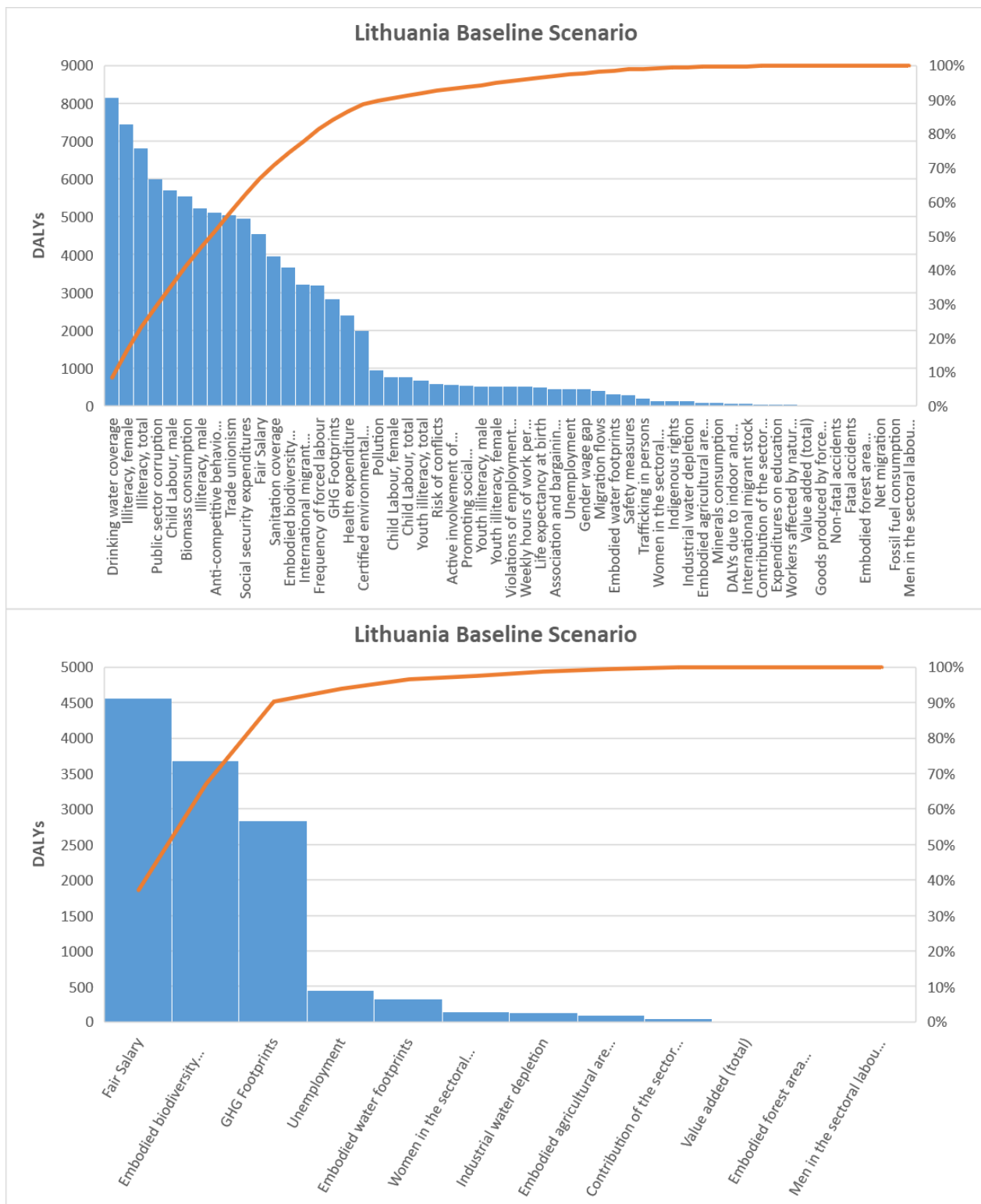


Figure 8: (**Top**) Pareto chart with S-LCA results from the Lithuanian Baseline scenario of the BEATLES project for 1 year of production showing all evaluated SOCA 2 indicators and (**Bottom**) same Pareto chart

simplified to include only the EU CAP-relevant indicators (The orange line is the Pareto line of aggregate percentages of the factors on the X axis)

The S-LCA analysis of the Lithuanian Baseline scenario resulted in total 96957.83 DALYs. The 4 most impactful factors were the Drinking water coverage (8163.93 DALYs), followed by Female adult illiteracy rate (7462.93 DALYs), Total adult illiteracy rate (6825,68 DALYs) and Public sector corruption (6008.15 DALYs). These factors account for ~30% of the total resulting DALYs. On the other hand, the least impactful factors were the Men sectoral labor force (0.90 DALYs), followed by Fossil fuel consumption (0.96 DALYs), Net migration (0.99 DALYs) and Embodied forest area footprints (1.52 DALYs). These contributed <0.005% to the total resulting DALYs.

Focusing on the CAP-relevant indicators that are more in accordance with the BEATLES project (Figure 8 Bottom), the 3 most important factors were the Fair Salary (4561.35 DALYs), followed by Embodied Biodiversity Footprints (3675.44 DALYs) and GHG Footprints (2832.19 DALYs). Judging by the relevant inputs and risk assessments in Table 10, these high risk results for the aforementioned indicators were not expected, as the associated risks ranged from medium (Fair Salary) to No Data-Low (Embodied biodiversity Footprints & GHG Footprints). However, since the analysis is conducted on a Life Cycle basis on global scale, there are several upstream flows that contribute to overall risks, and indeed it was found that most of the risks were associated with the flow related to the nutrients for the production of wheat seed for sowing on global scale, followed by production and use of diesel and the required herbicides. It is anticipated that a change in production flowcharts and/or the applied activity variables due to an application of a CSA practice might cause a desired reduction to some of these high-risk impacts.

3.2 Use Case Pilot #2: Dairy farming, Germany

3.2.1 Goal and Scope definition – German UC (dairy farm)

The **goal** of the assessments undertaken (LCA, LCC and s-LCA) is to conduct an environmental, economic, and social evaluation of the German UC baseline scenario. This scenario represents a conventional dairy farm that does not include any of the CSA practices that will be studied in next year activities. This evaluation will serve as a benchmark for the comparison with the alternative scenarios that incorporate the CSA practices.

For the definition of the **scope** of the study, after thorough communication with the German UC leader, process flow diagram depicting the baseline scenario (product system) has been developed. The studied UC is briefly outlined, accompanied by flowchart illustrating the process (Fig. 3), and supplemented with data collected from distributed questionnaires.

Product system:

The product system is a dairy farm that does not apply any of the CSA practices that will be studied in the next year's activities. This farm has been studied in this year's activities and will be compared with scenarios that include CSA practices in next year's activities. The main processes along with all the relative flows are presented in Figure 9.

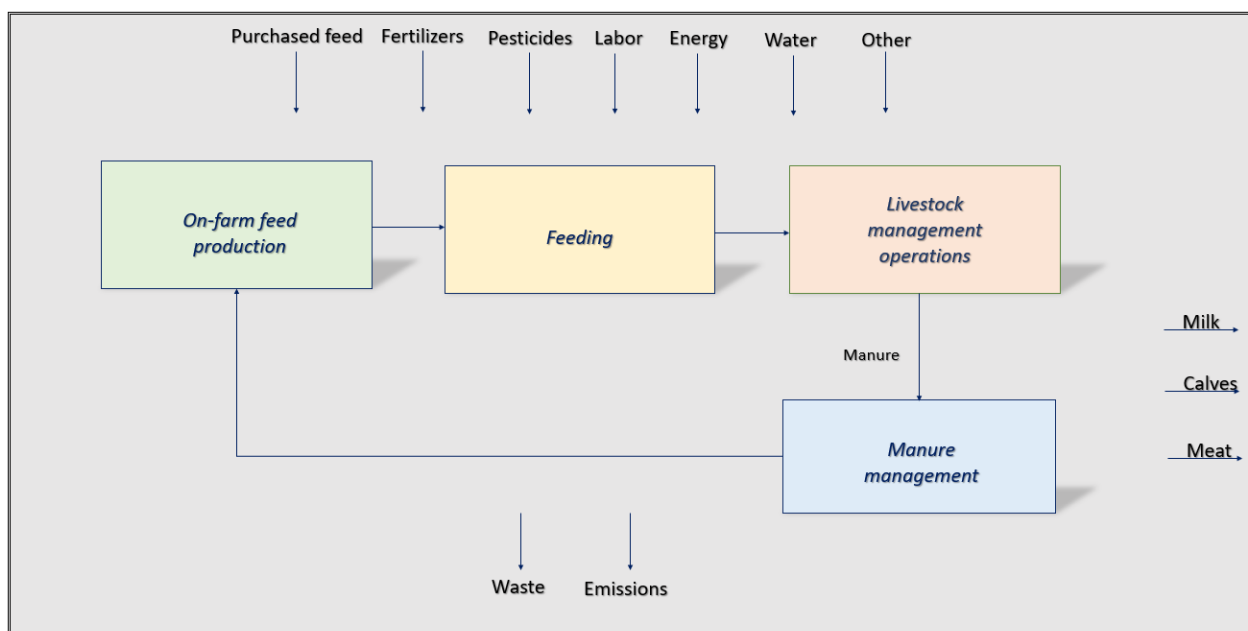


Figure 9: Flowchart of the German UC baseline scenario.

Functions of the product system: The main processes that were included within the product system were the following: feed production, feeding of livestock, management operations and manure management. The sustainability assessment considers the overall flows of the entire product system rather than individually for each process.

Functional unit: The functional unit has been defined as 1 cow (average live weight: 600 kg).

System boundaries: A cradle-to-gate approach has been selected for the sustainability evaluation of the product system, as the effect of the CSA practices that will be studied in the next year's activities is depicted on these stages. More specifically, the boundaries of the system encompass all the stages from the feed production till the livestock management within the farm as well as manure management.

Allocation procedures: Since there are no multiple products involved, no allocation is needed.

Environmental impact assessment methodology and types of impacts, and interpretation performed: ReCiPe 2016 (H, hierarchist) was used in order to convert the LCI data into a set of environmental impact scores using characterization factors. Detailed description of the method is provided in subsection 2.1.2.

Data requirements: To conduct the LCA analysis, data were gathered through the distribution of questionnaires to relevant stakeholders, supplemented by data from verified databases such as Ecoinvent and Agri-footprint, which cover the geographical area of the European Union 28 (EU-28). The collected data refer to the Bavaria region.

Assumptions/Limitations: The collected data correspond to a farm that is representative of a conventional dairy farm in the Bavaria region, that focuses on milk production, with an average of 60 cows replaced each year. Moreover, the dairy farm produces significant other co-products, including calves and beef meat.

3.2.2 Life Cycle Inventory (LCI) – German UC (dairy farm)

The next step after defining the goal and scope of the study was the life cycle data inventory, which linked all activities with quantitative data according to the selected functional unit. For the

development of the data inventory, appropriate questionnaires were prepared and provided to the UC leader for distribution to the relevant stakeholders (farmers, advisors, etc). Following data collection, validation and aggregation of these data were performed. Where necessary, supplementary databases (Ecoinvent, Agribalyse, Agri-footprint) or literature sources were used for the establishment of the LCI. The LCI inventory is presented in Table 12, with all flows aggregated using 1 cow (average weight: 600 kg) as the Functional Unit.

Parameter	Unit	Value	Data source
INPUTS			
Land use (FU)	ha	7499.66	Advisor Interview
Animals			
Cow	piece	1	Advisor Interview
Feedstock			
Maize silage	tonne	6.07	Advisor Interview
Grassland (silage)	tonne	0.67	
Soybeans	tonne	1.17	
Grain + catch crop	tonne	1.52	
Grain	tonne	1.87	
Fertilizers			
N	kg	108	Advisor Interview
P ₂ O ₅	kg	22.3	
K ₂ O	kg	29.1	
Energy			
Electricity	kWh	400	Advisor Interview
Water			
Water from public network	m ³	30	Advisor Interview
OUTPUTS			
Milk	kg	8000	Advisor Interview
Meat	kg	150	
Calves	piece	1.06	
Manure	kg	178	
Ammonia [Inorganic emissions to air]	kg	29.8	Literature [11]
Methane (biotic) [Organic emissions to air]	kg	99	
Nitrogen oxides [Emissions to non-urban air or from high stacks]	kg	82.14	
Carbon dioxide (fossil) [Renewable material resources from air]	kg	1.81	

Table 12: Life Cycle Inventory of a conventional farm – German UC, baseline scenario.

3.2.3 Environmental Life Cycle Impact Assessment (e-LCIA) – German UC (dairy farm)

LCA analysis was performed for the baseline scenario based on the data collected from the UC (Table 12), utilizing the SimaPro 9.6 software. For reference, the results of the impact assessment

of a relevant scenario reported in LCA for Experts database for a representative dairy farm in Germany are also presented in Tables 13 & 14.

Impact category	Unit	Baseline dairy farm (BEATLES) (per cow)	Baseline dairy farm (BEATLES) (per kg of milk, econ. alloc.)	Baseline dairy farm (LCA for Experts database) (per kg of milk)
Global warming (excluding biogenic carbon)	kg CO ₂ eq	4.20E+03	4.35E-01	1.33E+00
Stratospheric ozone depletion	kg CFC11 eq	9.45E+00	8.89E-07	1.11E-05
Ionizing radiation	kBq Co-60 eq	2.61E+02	4.74E-04	3.80E-04
Ozone formation, Human health	kg NO _x eq	7.89E+00	3.77E-02	3.71E-02
Fine particulate matter formation	kg PM _{2.5} eq	1.40E+00	9.79E-04	9.52E-03
Ozone formation, Terrestrial ecosystems	kg NO _x eq	8.19E-02	6.07E-02	5.82E-02
Terrestrial acidification	kg SO ₂ eq	2.25E-01	7.47E-03	1.85E-02
Freshwater eutrophication	kg P eq	1.98E+03	8.49E-06	2.37E-04
Marine eutrophication	kg N eq	4.58E+00	8.19E-05	2.20E-03
Terrestrial ecotoxicity	kg 1,4-DCB	1.13E+04	1.52E-02	5.65E-02
Freshwater ecotoxicity	kg 1,4-DCB	1.82E+00	1.45E-04	9.76E-04
Marine ecotoxicity	kg 1,4-DCB	7.91E-01	1.89E-04	1.24E-03
Human carcinogenic toxicity	kg 1,4-DCB	1.20E+01	2.34E-05	1.26E-04
Human non-carcinogenic toxicity	kg 1,4-DCB	5.86E+02	2.05E-01	-2.84E-01
Land use	m ² a crop eq	3.64E+02	1.17E+00	1.52E+00
Mineral resource scarcity	kg Cu eq	8.58E-03	1.25E-03	6.95E-03
Fossil resource scarcity	kg oil eq	7.21E+01	2.70E-02	7.33E-02
Water consumption	m ³	1.47E+02	8.18E-04	4.15E-02

Table 13: Results of impact assessment of the German UC baseline scenario (based on data collected by UC leader for a conventional dairy farm) per cow per year– midpoint indicators. Results of a relevant scenario based on data obtained from LCA for experts database are presented in the final column.

Impact category	Unit	Baseline dairy farm (BEATLES) (per cow)	Baseline dairy farm (BEATLES) (per kg of milk, econ. alloc.)	Baseline dairy farm (LCA for Experts database) (per kg of milk)
Ecosystems	species.yr	3.09E-03	3.20E-07	3.21E-08

Damage to Human health	DALY	1.88E-03	1.95E-07	8.25E-06
Resources	USD2013	4.07E+03	4.22E-01	3.10E-02

Table 14: Results of impact assessment of the German UC baseline scenario (based on data collected by UC leader for a conventional dairy farm) per cow per year – endpoint indicators. Results of a relevant scenario based on data obtained from LCA for experts database are presented in the final column.

Table 13 lists the annual average impacts per cow for the 18 midpoint impact categories under investigation, based on the methodology followed (ReCiPe 2016, H). The UC farm presents many similarities with the scenario of LCA for experts database in various important categories, including Ionizing Radiation, Ozone Formation, Terrestrial and Freshwater Ecotoxicity, Land use, and Mineral and Fossil Resource Scarcity. Any differences in the rest of the midpoint impact categories may be due to variations in the farm conditions. The results of the environmental assessment of the baseline scenario will be used in the next year's activities as a benchmark for comparison with scenarios that include the application of selected CSA practices.

A detailed percentage distribution of the contribution of each agricultural input in the 18 midpoint impact categories is presented in Table 15. The effect of each input in selected midpoint impact categories is also presented in Figure 10.

Impact category	Unit	Electricity	Soybeans	Grassland (silage)	Maize silage	Water	Fertilizers	Emissions (dairy farm)
Global warming	kg CO2 eq	6.05%	1.49%	1.05%	4.38%	0.00%	6.81%	80.23%
Stratospheric ozone depletion	kg CFC11 eq	1.42%	0.10%	15.74%	39.52%	0.00%	43.23%	0.00%
Ionizing radiation	kBq Co-60 eq	84.55%	0.38%	0.00%	7.91%	0.00%	7.16%	0.00%
Ozone formation, Human health	kg NOx eq	82.67%	3.32%	0.00%	5.99%	0.00%	8.01%	0.00%
Fine particulate matter formation	kg PM2.5 eq	0.86%	0.18%	2.48%	2.62%	0.00%	8.02%	85.84%
Ozone formation, Terrestrial ecosystems	kg NOx eq	82.77%	3.33%	0.00%	5.91%	0.00%	7.99%	0.00%
Terrestrial acidification	kg SO2 eq	0.37%	0.07%	2.43%	1.64%	0.00%	3.66%	91.84%
Freshwater eutrophication	kg P eq	1.31%	0.97%	0.00%	97.30%	0.00%	0.42%	0.00%
Marine eutrophication	kg N eq	0.96%	0.25%	0.01%	98.53%	0.00%	0.24%	0.00%
Terrestrial ecotoxicity	kg 1,4-DCB	57.36%	1.50%	0.32%	8.59%	0.00%	32.22%	0.00%
Freshwater ecotoxicity	kg 1,4-DCB	1.11%	0.32%	3.66%	41.82%	0.00%	53.10%	0.00%
Marine ecotoxicity	kg 1,4-DCB	3.01%	0.70%	2.92%	38.99%	0.00%	54.38%	0.00%
		6.05%	1.49%	1.05%	4.38%	0.00%	6.81%	80.23%

Table 15: Percentage contribution of each flow in the various midpoint indicators – German UC, baseline scenario.

Impact category	Unit	Electricity	Soybeans	Grassland (silage)	Maize silage	Water	Fertilizers	Emissions (dairy farm)
Human carcinogenic toxicity	kg 1,4-DCB	16.77%	6.48%	1.53%	32.78%	0.01%	42.44%	0.00%
Human non-carcinogenic toxicity	kg 1,4-DCB	-0.31%	0.10%	0.09%	98.35%	0.00%	1.78%	0.00%
Land use	m ² a crop eq	0.18%	0.00%	27.33%	9.32%	0.00%	0.01%	63.17%
Mineral resource scarcity	kg Cu eq	3.79%	1.14%	0.00%	69.26%	0.01%	25.81%	0.00%
Fossil resource scarcity	kg oil eq	27.94%	6.60%	2.17%	12.28%	0.00%	51.01%	0.00%
Water consumption	m ³	11.31%	0.54%	0.00%	85.81%	0.38%	1.96%	0.00%

Table 15: Percentage contribution of each flow in the various midpoint indicators – German UC, baseline scenario (continued).

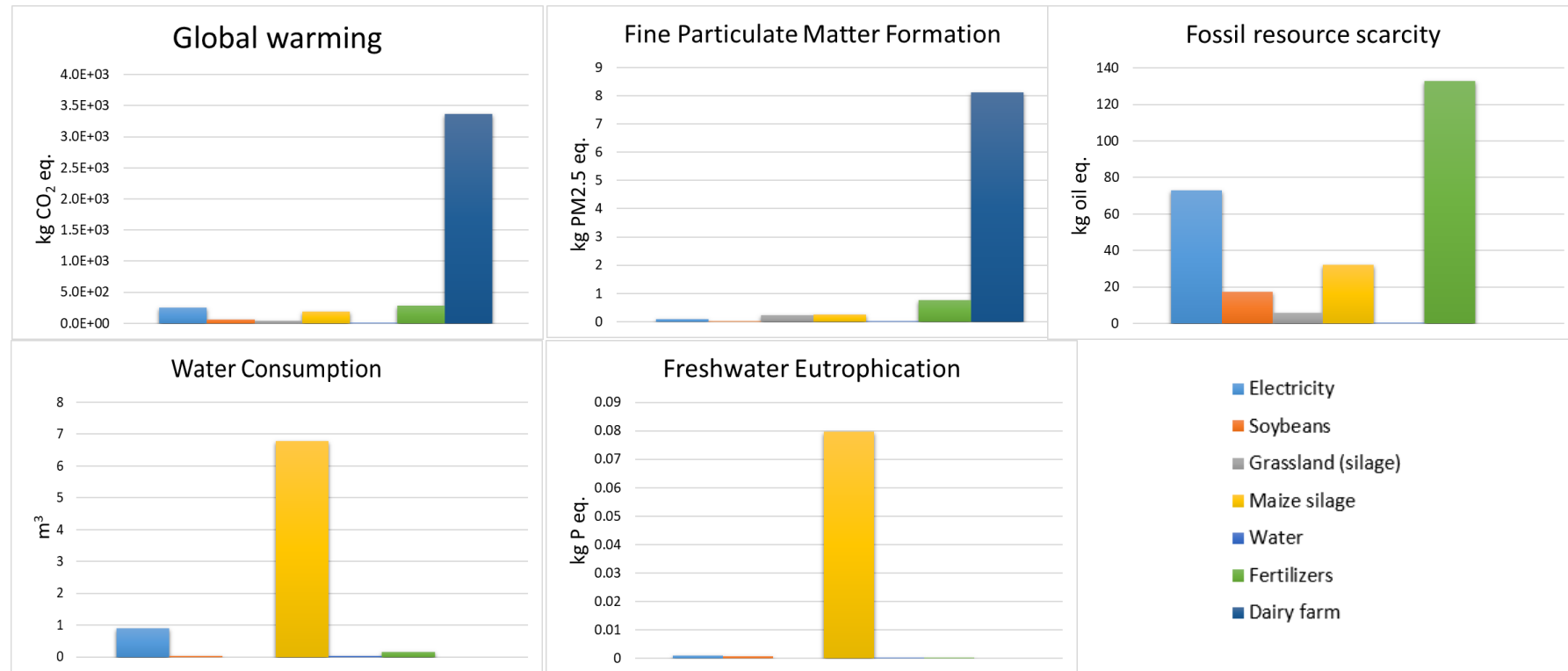


Figure 10: Contributing processes to the midpoint impacts per cow per year for the baseline scenario – German UC.

By analyzing the contributions of the dairy farm to each impact category, it can be observed that the emissions from the enteric fermentation, the use of fertilizers and the cultivation of maize are responsible for the highest attribution to many impact categories. Global warming is mainly affected (at a percentage 80%) by the emissions originating from the dairy farm, similarly to the fine particulate matter formation. Moreover, these emissions contributed significantly to the terrestrial acidification due to NH_3 and NO_x emissions. Fossil resource scarcity is affected by the use of electric energy (28%) as well as by the production of synthetic fertilizers (51%). The feed and especially the maize production had the main effect on water consumption, due to irrigation needs of the cultivars, as well as to the freshwater eutrophication, due to the use of pesticides and fertilizers.

3.2.4 Interpretation of LCA results - German UC (dairy farm)

The main environmental impact of the German UC on each midpoint impact category is attributed to the emissions from the enteric fermentation and the use of fertilizers for feed production. The objectives of next year's studies will involve evaluating the potential of the selected CSA practices to reduce this impact in key categories, including global warming, fine particulate matter formation, fossil resource scarcity, and water or marine ecotoxicity and eutrophication, through outcomes such as energy credits and decrease of emissions from manure management or feed production.

3.2.5 Life Cycle Cost Analysis (LCC) – German UC (dairy farm)

For the calculation of the annual life cycle costs of dairy farm (German UC, baseline scenario), Only OpEx was taken into account as any equipment, land, building or other CapEx are considered to have been depreciated and only maintenance costs are taken into account. In Figure 11 the expenditures are presented, along with the revenues including subsidies and sale of milk, meat and calves. Labor costs were not taken into consideration, as the studied farm is a family-run operation, and the profit directly reflects the farmer's revenues. The highest OpEx include the annual replacement of the cows, the purchase of part of their feed and the maintenance costs. The main income of the farm occurs from the sale of the milk, whereas a small financial contribution is also provided by meat products and calves. The profit of the farm that corresponds to the income of the farmer is calculated up to 1167€ per cow per year.

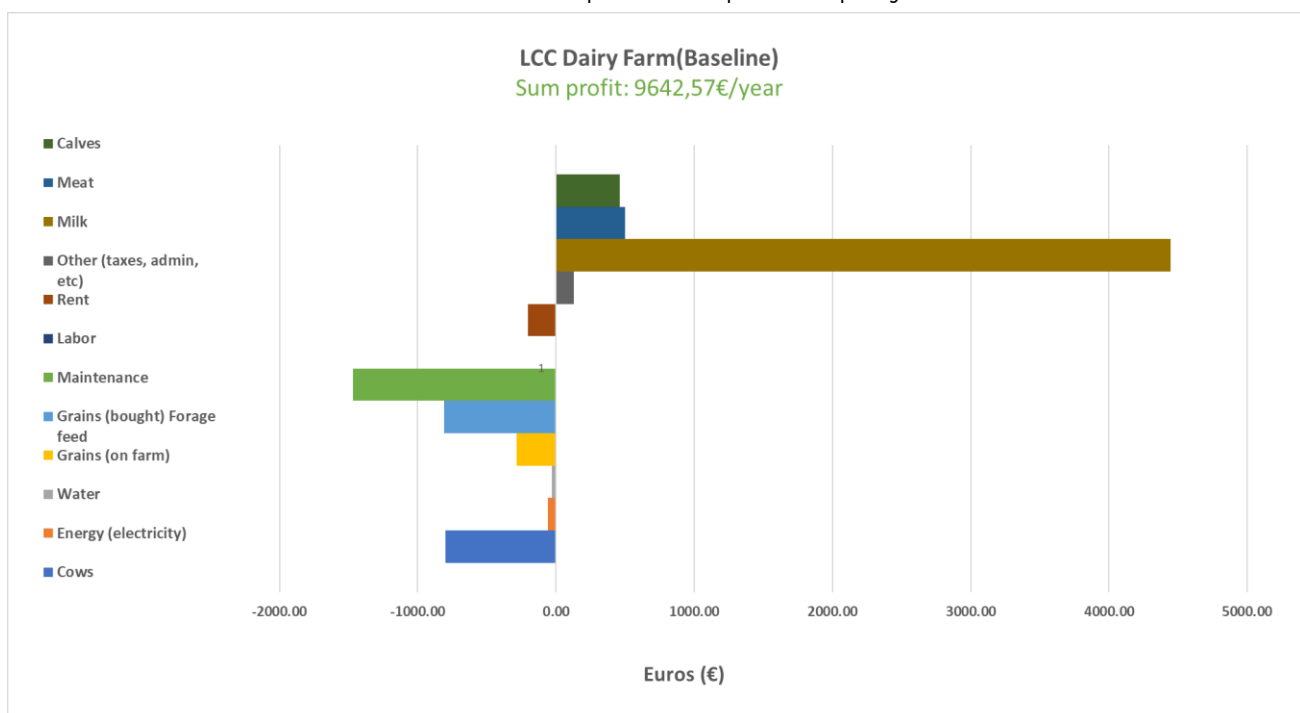


Figure 11: Life Cycle Cost Analysis of the German UC per cow per year, baseline scenario (Positive values correspond to annual revenues, negative values correspond to annual expenses).

3.2.6 Social Life Cycle Impact Assessment (s-LCIA) and interpretation of results – German UC (dairy farm)

The production flows and relevant inventory data of the German Baseline scenario were taken from the resulting LCIA shown in previous section 3.2.2. Data inputs and calculated results for the social indicators of the German Baseline scenario are presented in Table 16. Values in bold were values taken directly from the distributed questionnaire, while values with normal fonts were taken directly from the data sources presented in Table 4. Regarding the “Worker hours” activity variable, data for the sectoral parameters was taken from Eora 2019 and ILOStat databases. The Unit labor cost was calculated based on an annual production of 476340 kg milk and an average annual compensation of 298422.46 €. The hourly labor costs were calculated assuming 4.5 weeks/month. Using the values from the databases, the activity variable “Worker hours” was calculated as follows. The activity variable was used in every indicator and the respective DALYs were calculated. Note that some indicators give combined results (e.g. the 3 wage indicators have combined output as “Fair Salary” - see Table 16 & Figure 12):

$$\text{Unit Labour Costs} = \frac{40483.2}{476340} = 0.0850 \text{ €}$$

and

$$\text{Worker hours} = \frac{0.0850 \text{ €}}{22.9905 \text{ €/h}} = 0.3823 \text{ h}$$

Indicator	Value	Risk level	Calculated DALYs
Children in employment, male	No Data	No Data	143788.54
Children in employment, female	No Data	No Data	12439.63
Children in employment, total	No Data	No Data	12376.78
Frequency of forced labor	0.6	Very Low	24407.22
Good produced by forced labor	No Data	No Data	314.61
Trafficking in persons	1	Very Low	3482.36
Living wage, per month	1240	Very High	-
Minimum wage, per month	0.58	Low	-
Sector average wage, per month	1.57 & 2.72	Very Low	-
Fair Salary	-	-	51112.74
Hours of work per employee, per week	32.6	Medium	13344.08
Women in the sectoral labor force	0.5	Medium	3405.27
Men in the sectoral labor force	0.5	Medium	17.54
Gender wage gap	20.42%	High	10185.25
Accident rate at workplace, non-fatal	1320.6	Low	338.34
Accident rate at workplace, fatal	2.5	Very Low	156.11
DALYs due to indoor and outdoor air and water pollution	7.69	Low	1443.61
Presence of sufficient safety measures	23.5	Low	9411.06
Workers affected by natural disasters	0.7660%	Very Low	487.39
Social security expenditures	19.05%	Low	132211.32
Evidence of violations of laws & employment regulations	0.1<y<1	Low	5320.74
Trade union density	16.3	Very High	134270.15
Right of Association	2	Low	-
Right of Collective bargaining	2	Low	-
Right to Strike	2	Low	-
Association and Bargaining rights	-	-	1908.36
Presence of anti-competitive behavior or violation of anti-trust & monopoly legislation	0.0461	Very Low	140688.52
Public sector corruption	78	Low	149991.24
Active involvement of enterprises in corruption & bribery	4%	Low	11917.83
Membership for social responsibility along supply chain	7%	Medium	5847.88
Global Peace Index (Risk of Conflicts)	1.46%	Low	14883.95
Contribution of the sector to economic development	0.86	No Opportunity	615.58
Value added (total)	-	-	346.03
Public expenditure on education	7.92	Low	1326.69

Adult illiteracy rate (15+ years), male	0	Very Low	133696.58
Adult illiteracy rate (15+ years), female	1	Very Low	139595.63
Adult illiteracy rate (15+ years), total	1	Very Low	137342.56
Youth illiteracy rate, male	0	Very Low	13433.40
Youth illiteracy rate, female	0	Very Low	13405.60
Youth illiteracy rate, total	0	Very Low	13797.90
Health expenditure, total	12.80%	Low	-
Health expenditure, public	78.40%	Low	-
Health expenditure, out-of-pocket	12.50%	Low	-
Health expenditure, external resources	No Data	No Data	-
Health expenditure	-	-	55971.46
Life expectancy at birth	81	No Risk	11102.96
Violations of mandatory health and safety standards	18E-7	High	-
Level of industrial water use (Total Withdrawal)	62.08%	Very High	-
Level of industrial water use (Renewable resources)	11.48%	High	-
Industrial water depletion	-	-	2173.14
Extraction of materials per population (Fossil fuels)	1.35	Very Low	19.27
Extraction of materials per population (Ores)	0.01	Very Low	-
Extraction of materials per population (Minerals)	7.36	Medium	-
Minerals' consumption	-	-	1668.47
Extraction of materials per population (Biomass)	2.93	Low	-
Extraction of materials per area (Biomass)	682.23	High	-
Biomass consumption	-	-	144473.24
Certified Environmental Management Systems	No	Very High	7901.11
Presence of indigenous population	No	No risk	-
Indigenous Rights Protection Index	4	Low	-
Indigenous rights	-	-	2214.49
Pollution level of the country	29.2	Low	17403.78
Drinking water coverage (urban, rural, total)	99.64% & 100%	Very Low & No	156068.96
Sanitation coverage (urban, rural, total)	91.39% & 98.47%	Low & Very Low	42092.36
Unemployment rate	3.1	Low	9888.87
International migrant workers in the sector	0	No Risk	24720.89
International migrant stock	14.9	High	1412.28
Net migration rate	1.8	Very Low	51.14
Immigration rate	0.01369	Medium	-
Emigration rate	0.00897	High	-
Asylum seekers rate	3.39E-04	Low	-
Migration flows	-	-	3963.78
GHG Footprints	No Data	No Data	24376.76
Embodied agricultural area footprints	No Data	No Data	678.67
Embodied biodiversity footprints	No Data	No Data	37639.82
Embodied forest area footprints	No Data	No Data	84.35
Embodied water footprints	No Data	No Data	4454.47

Table 16: S-LCA Data for the German Baseline scenario of the BEATLES project: Indicator values, associated risk levels and calculated DALYs for 1 year of production (Values in **bold** are data taken from the distributed questionnaire)

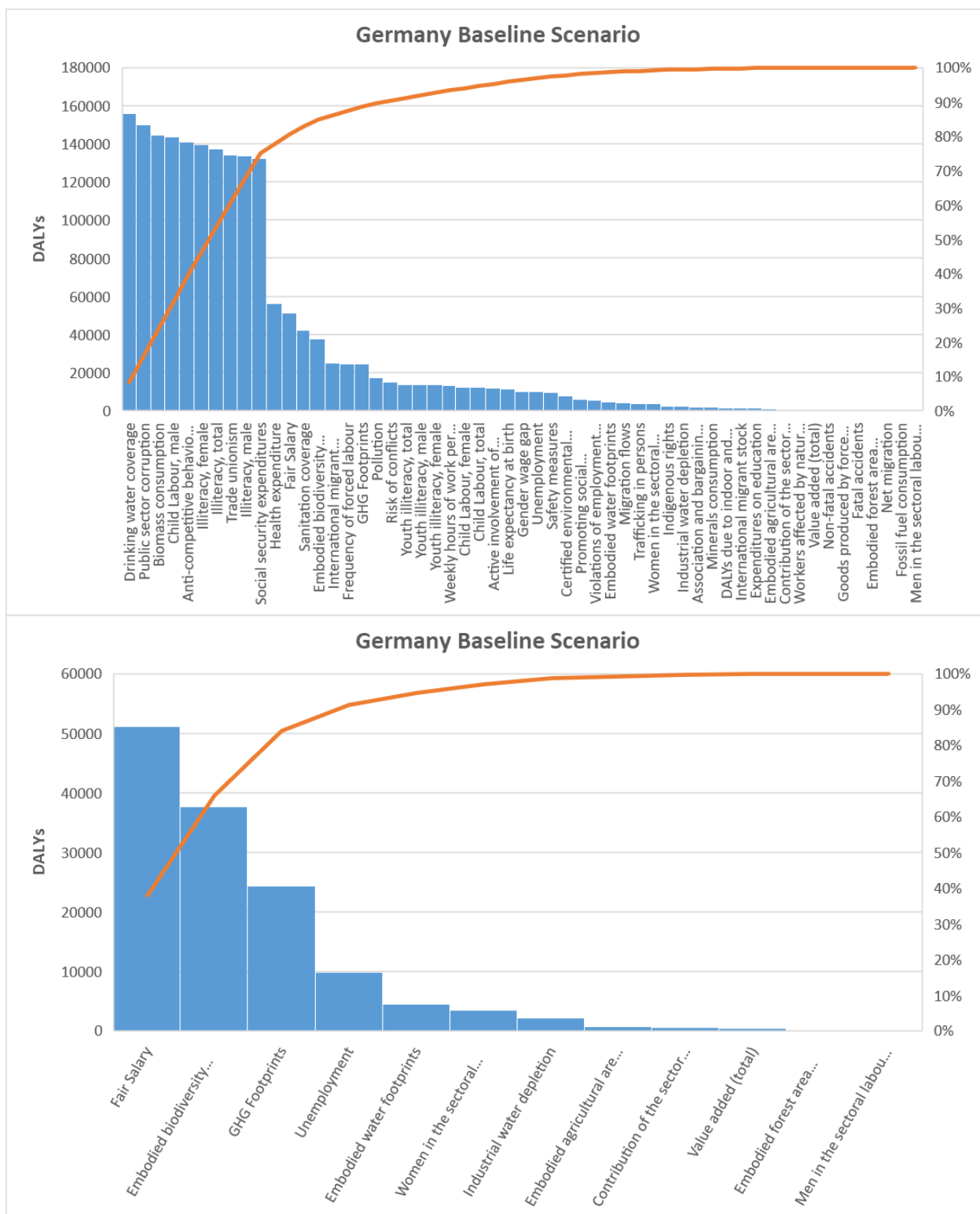


Figure 12: **(Top)** Pareto chart with S-LCA results from the German Baseline scenario of the BEATLES project for 1 year of production showing all evaluated SOCA 2 indicators and **(Bottom)** same Pareto chart simplified to include only the EU CAP-relevant indicators (The orange line is the Pareto line of aggregate percentages of the factors on the X axis)

The S-LCA analysis of the German Baseline scenario resulted in total 1885670.76 DALYs. Most of them resulted from 10 factors, namely the Drinking water coverage (156068.96 DALYs), followed by Public sector corruption (14991.24 DALYs), Biomass consumption (144473.24 DALYs), Male child

labor (143788.54 DALYs), Anti-competitive behavior (140688.52 DALYs), Female illiteracy rate (139595.63 DALYs), Total illiteracy rate (137342.56 DALYs), Trade unionism (134270.15 DALYs), Male illiteracy rate (133696.58 DALYs) and Social security expenditures (132211.32 DALYs). These factors account for ~75% of the total resulting DALYs. On the other hand, the least impactful factors were the Men sectoral labor force (17.54 DALYs), followed by Fossil fuel consumption (19.27 DALYs) and Net migration (51.14 DALYs). These contributed <0.005% to the total resulting DALYs.

Focusing on the CAP-relevant indicators that are more in accordance with the BEATLES project (Figure 12 Bottom), the 4 most important factors were the Fair Salary (51112.74 DALYs), followed by Embodied Biodiversity Footprints (37639.82 DALYs), GHG Footprints (24376.76 DALYs) and Unemployment rate (9888.87 DALYs). Judging by the relevant inputs and risk assessments in Table 15, these high-risk results for the aforementioned indicators were not expected, as the associated risks ranged from No Data-Low (Embodied biodiversity Footprints, GHG Footprints, Unemployment rate) to very low (Fair Salary). However, since the analysis is conducted on a Life Cycle basis on global scale, there are several upstream flows that contribute to overall risks, and indeed it was found that most of the risks were associated with the flow related to the animal housing operation on global scale (more specifically to the required low voltage electricity), followed by production and use of fertilizers and animal feed. It is anticipated that a change in production flowcharts and/or the applied activity variables due to an application of a CSA practice might cause a desired reduction to some of these high-risk impacts.

3.3 Use Case Pilot #3: Apple farming, Spain

3.3.1 Goal and Scope definition – Apple farming, Spain

The **goal** of the assessments undertaken (LCA, LCC and s-LCA) is to conduct an environmental, economic, and social evaluation of the Spanish UC baseline scenario. This scenario represents a conventional apple farm that does not include any of the CSA practices that will be studied in next year activities. This evaluation will serve as a benchmark for the comparison with the alternative scenarios that incorporate the CSA practices.

For the definition of the **scope** of the study, after thorough communication with the Spanish UC leader, process flow diagram depicting the baseline scenario (product system) has been developed. The studied UC is briefly outlined, accompanied by flowchart illustrating the process (Fig. 13), and supplemented with data collected from distributed questionnaires.

Product system:

The product system is a dairy farm that does not apply any of the CSA practices that will be studied in the next year's activities. This farm has been studied in this year's activities and will be compared with scenarios that include CSA practices in next year's activities. The main processes along with all the relative flows are presented in Figure 13.

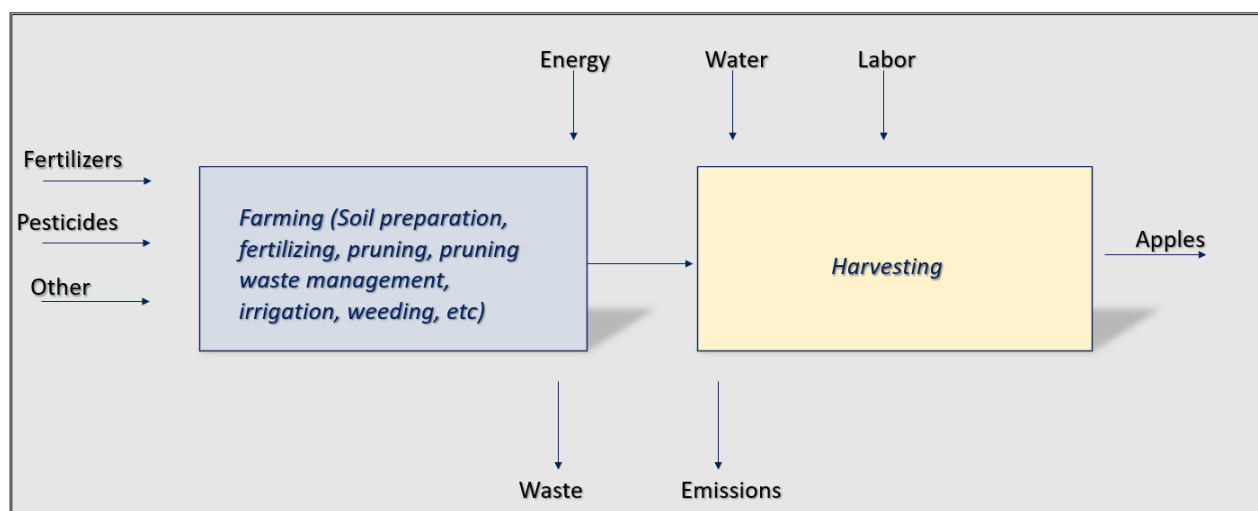


Figure 13: Flowchart of the Spanish UC baseline scenario.

Functions of the product system: The main processes that are included within the product system are the following: farming (including sub-processes, such as soil preparation, fertilizing, pruning, pruning waste management, irrigation, weeding, etc) and harvesting of apples.

System boundaries: A cradle-to-gate approach has been selected for the sustainability evaluation of the product system, as the effect of the CSA practices that will be studied in the next year's activities is depicted on these stages. More specifically, the boundaries of the system encompass all the stages from the soil preparation till the harvesting of the apples.

Allocation procedures: Since there are no multiple products involved, no allocation is needed.

Environmental impact assessment methodology and types of impacts, and interpretation to be performed: ReCiPe 2016 (H, hierarchist) will be used in order to convert the LCI data into a set of environmental impact scores using characterization factors. Detailed description of the method is provided in subsection 2.1.2.

Data requirements: To conduct the LCA analysis, data were gathered through the distribution of questionnaires to relevant stakeholders, supplemented by data from verified databases such as Ecoinvent, Agri-footprint and Agribalyse, which cover the geographical area of the European Union 28 (EU-28). The collected data refer to the last year (2023).

Assumptions/Limitations: The collected data correspond to a farm representative of a conventional apple orchard in Navarra. It produces Golden variety apples, in the south of the Navarra region, with an area of 1 ha and an irrigation system. None of the CSA practices, that will be studied in the next year's activities, are applied on this product system.

3.3.2 Life Cycle Inventory (LCI) – Apple farming, Spain

The next step after defining the goal and scope of the study is the life cycle data inventory, which links all activities with quantitative data according to the selected functional unit. For the development of the data inventory, appropriate questionnaires were prepared and provided to the UC leader for distribution to the relevant stakeholders (farmers, advisors, etc). Following data collection, validation and aggregation of these data were performed. Where necessary, supplementary data from appropriate databases (Ecoinvent, Agribalyse, Agri-footprint) or literature sources were used for the establishment of the LCI. The inventory is presented in Table 17, with all flows aggregated using 1 ha of cultivated land as the Reference Flow. The results are presented per 1 kg of harvested apples, using this as the functional unit.

Parameter	Unit	Value	Data source
INPUTS			
Land use	ha	1	Farmer/advisor interview
Fertilizers			
NPK (8-4-10)	kg	1100	Farmer/advisor interview
Potassium nitrate (NPK: 13-0-46)	kg	100	
Calcium	kg	3	
Fungicides			
Fungicide #1 (oxicloruro)	Kg	2	Farmer/advisor interview
Fungicide #2 (Tebuconazol)	L	0.6	
Fungicide #3 (Difenoconazol)	L	0.15	
Fungicide #4 (Captan)	L	1.5	
Fungicide #5 (Luna experience)	L	0.2	
Fungicide #6 (Bellis)	L	0.8	
Fungicide #7 (Sercadis)	L	0.3	
Fungicide #8 (mimic)	L	0.75	
Insecticides			
Insecticide #1 (Movento Gold)	L	1.5	Farmer/advisor interview
Insecticide #2 (Flash UM)	L	1.25	
Insecticide #3 (Scatto)	L	0.5	
Insecticide #4 (Piriproxifen)	L	0.5	
Insecticide #5 (Cidetrak CM meso)	ud	100	
Insecticide #6 (Acetaprimid)	Kg	0.35	
Herbicides			
Herbicide #1 (Diflufenican)	L	1	Farmer/advisor interview
Herbicide #2 (Glifosato)	L	3	
Phytoregulator			
Phytoregulator #1 (Maxcel)	L	0.55	Farmer/advisor interview
Phytoregulator #2 (Ana)	kg	0.12	
Other chemicals			
Paraffin oil	L	6	Farmer/advisor interview
Energy			
Diesel	L	825	Farmer/advisor interview
Water			
Water from public network	L	6.36E03	Farmer/advisor interview
OUTPUTS			
Apples	tonne	35	Farmer interview
Pesticides [Emissions to fresh water]	kg	2.14	Literature [10]
Pesticides [Emissions to agricultural soil]	kg	6.68E-04	
Pesticides [Emissions to air]	kg	6.27E-01	

Table 17: Life Cycle Inventory of a conventional apple orchard – Spanish UC, baseline scenario. The values are given per ha per year.

The estimation of the initial emission distribution fractions of the applied chemical agents (fungicides, herbicides, insecticides and phytoregulators) was based on emission modelling for pesticides provided in literature [10]. More specifically, the emissions to soil, water and air were estimated based on the percentage of the active compound per case and the appropriate coefficients provided for the category of temperate fruit trees.

3.3.3 Environmental Life Cycle Impact Assessment (e-LCIA) – Apple farming, Spain

LCA analysis was performed for the baseline scenario based on the data collected from the UC, utilizing the SimaPro 9.6 software. For reference, along with the total environmental effect of apples production for the baseline scenario, the results of the impact assessment of a relevant scenario with data available in Ecoinvent database for apples production in Italy are also presented in Tables 18 & 19. Due to lack of average data for apples production in Spain, data regarding the apples production in Italy have been used, as these countries belong to the same geographical region (southern Europe) and share similar climatic conditions.

Impact category	Unit	Baseline apple farm (BEATLES)	Baseline apple farm (Ecoinvent)
Global warming (excluding biogenic carbon)	kg CO ₂ eq	2.04E-02	3.12E-02
Stratospheric ozone depletion	kg CFC11 eq	1.93E-08	3.35E-07
Ionizing radiation	kBq Co-60 eq	1.02E-04	1.11E-03
Ozone formation, Human health	kg NO _x eq	7.76E-03	1.37E-04
Fine particulate matter formation	kg PM _{2.5} eq	1.26E-05	7.49E-05
Ozone formation, Terrestrial ecosystems	kg NO _x eq	1.25E-02	1.40E-04
Terrestrial acidification	kg SO ₂ eq	4.39E-05	3.08E-04
Freshwater eutrophication	kg P eq	3.79E-07	3.64E-05
Marine eutrophication	kg N eq	2.04E-06	6.80E-06
Terrestrial ecotoxicity	kg 1,4-DCB	2.22E-02	7.41E-02
Freshwater ecotoxicity	kg 1,4-DCB	6.28E-04	3.75E-03
Marine ecotoxicity	kg 1,4-DCB	1.14E-03	1.56E-03
Human carcinogenic toxicity	kg 1,4-DCB	2.08E-05	3.28E-04
Human non-carcinogenic toxicity	kg 1,4-DCB	6.83E-03	-1.10E-01
Land use	m ² a crop eq	2.06E-01	1.76E-01
Mineral resource scarcity	kg Cu eq	3.39E-03	9.55E-05
Fossil resource scarcity	kg oil eq	2.63E-02	6.48E-03
Water consumption	m ³	2.98E-04	4.46E-02

Table 18: Results of impact assessment of the Spanish UC baseline scenario (based on data collected by UC leader for a conventional apple farm) per 1 kg of apples per year – midpoint indicators. Results of a corresponding scenario based on data obtained from Ecoinvent database are presented in the final column.

Impact category	Unit	Baseline apple farm (BEATLES)	Baseline apple farm (Ecoinvent)
Ecosystems	species.yr	1.73E-09	2.61E-09
Damage to Human health	DALY	5.13E-08	1.54E-07
Resources	\$	1.25E-02	2.35E-03

Table 19: Results of impact assessment of the Spanish UC baseline scenario (based on data collected by UC leader for a conventional apple farm) per 1 kg of apples per year – endpoint indicators. Results of a relevant scenario based on data obtained from Ecoinvent database are presented in the final column.

Table 18 lists the annual average impacts per kg of produced apples for the 18 midpoint impact categories under investigation, based on the methodology followed (ReCiPe 2016, H). The UC farm

presents many similarities with the scenario of Ecoinvent in various important categories, including Global Warming, Ozone Depletion, Fine Particulate Matter, Land Use, Marine Eutrophication, and Terrestrial, Freshwater and Marine Ecotoxicity. Any differences in other midpoint impact categories, such as Fossil Resource Scarcity or Water Consumption may be due to differences in machine utilization (diesel consumption) or irrigation needs, respectively. The results of the environmental assessment of the UC scenario will be used in the next year activities as a baseline for comparison with scenarios that include the application of selected CSA practices.

A detailed percentage distribution of the contribution of each agricultural input in the 18 midpoint impact categories is presented in Table 20. The effect of each input in selected midpoint impact categories is also presented in Figure 14.

Impact category	Unit	Irrigation	Fertilizers	Plant protection products	Energy (diesel)	Paraffin oil	Emissions (chemical agents)
Global warming	kg CO2 eq	0.09%	42.95%	5.19%	50.98%	0.85%	0.00%
Stratospheric ozone depletion	kg CFC11 eq	0.06%	23.28%	6.34%	70.47%	0.37%	0.00%
Ionizing radiation	kBq Co-60 eq	0.16%	64.28%	5.62%	28.82%	0.89%	0.00%
Ozone formation, Human health	kg NOx eq	0.11%	55.94%	9.72%	33.76%	0.51%	0.00%
Fine particulate matter formation	kg PM2.5 eq	0.31%	13.29%	8.96%	76.11%	0.99%	0.00%
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.11%	55.96%	9.71%	33.68%	0.51%	0.00%
Terrestrial acidification	kg SO2 eq	0.22%	12.03%	8.31%	78.59%	0.96%	0.00%
Freshwater eutrophication	kg P eq	0.01%	3.61%	1.86%	94.46%	0.12%	0.00%
Marine eutrophication	kg N eq	0.02%	4.45%	1.38%	94.12%	0.13%	0.00%
Terrestrial ecotoxicity	kg 1,4-DCB	0.01%	3.80%	1.08%	12.88%	0.34%	81.98%
Freshwater ecotoxicity	kg 1,4-DCB	0.00%	0.05%	0.04%	2.04%	0.02%	97.93%
Marine ecotoxicity	kg 1,4-DCB	0.00%	0.08%	0.05%	3.41%	0.03%	96.49%
Human carcinogenic toxicity	kg 1,4-DCB	0.02%	4.59%	2.17%	86.06%	0.72%	6.30%
Human non-carcinogenic toxicity	kg 1,4-DCB	0.02%	-0.37%	0.54%	98.10%	0.57%	1.09%
Land use	m ² a crop eq	0.00%	0.09%	0.03%	2.71%	0.00%	97.09%
Mineral resource scarcity	kg Cu eq	0.00%	98.48%	0.18%	1.24%	0.00%	0.00%
Fossil resource scarcity	kg oil eq	0.01%	12.34%	1.86%	85.17%	0.73%	0.00%
Water consumption	m ³	61.07%	4.48%	1.85%	32.62%	0.05%	0.00%

Table 20: Percentage contribution of each flow in the various midpoint indicators – Spanish UC, baseline scenario.

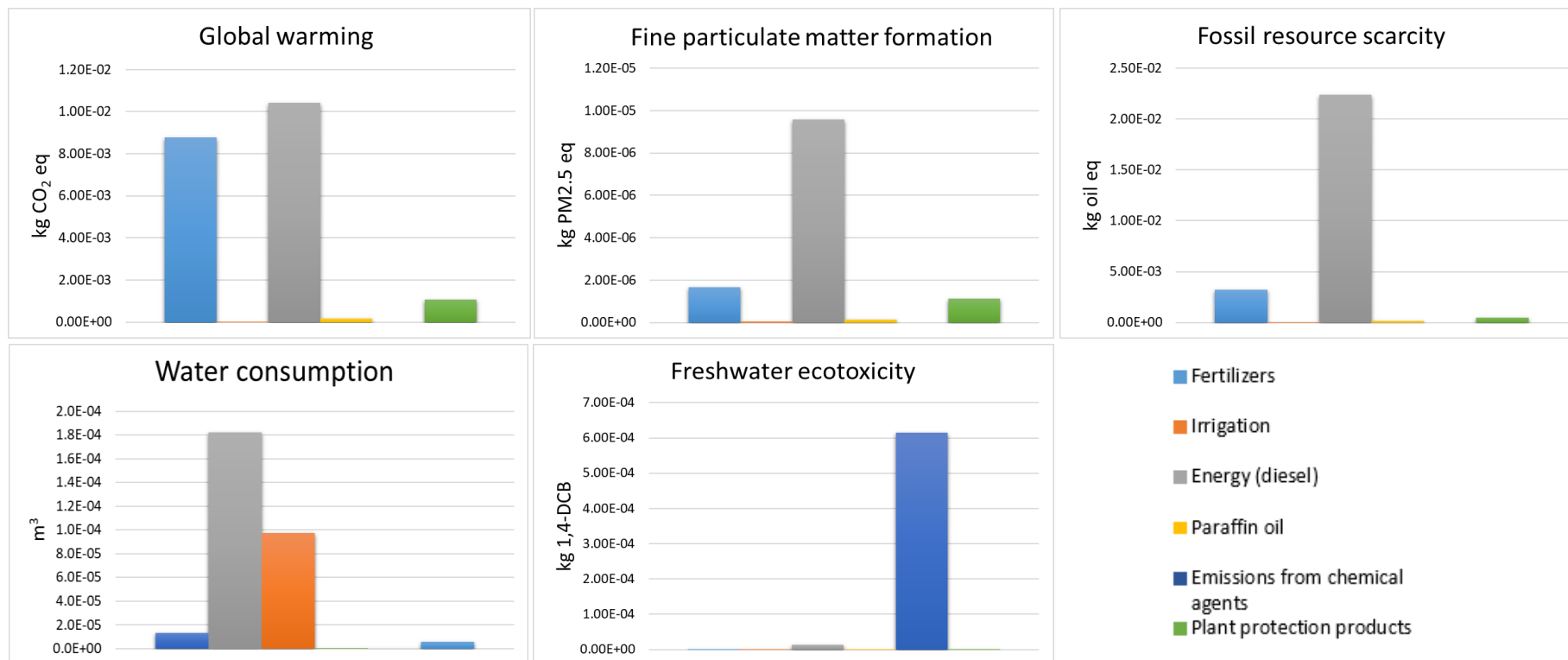


Figure 14: Contributing processes to the midpoint impacts per kg of apples for the baseline scenario per 1 kg of apples per year – Spanish UC

By analyzing the contributions of the apple orchard to each impact category for all inputs used, it can be observed that the use of diesel is the main contributor to many impact categories, followed by the use of synthetic fertilizers. The greatest percentage of contribution to the global warming impact is observed by the use of diesel for energy production related to farming activities and the application of plant protection products (fungicides, herbicides, insecticides, etc) or synthetic fertilizers. The impact of fertilizers primarily stems from the embodied impacts associated with the production of large volumes of micronutrient fertilizers applied and from the nitrous oxide emissions due to the use of nitrogen fertilizers. Fossil resource scarcity, as expected, is attributed to the use of fossil fuels (diesel) for the farming activities, at a percentage of 85.2%. The rest of the impact on this category is attributed to the fossil fuels used for energy production during the manufacture of the synthetic fertilizers and the plant protection products. Equally expected, the water consumption is mainly due to the irrigation of the orchard; a smaller share of this impact (about 33% and 4-5%, respectively) is attributed to the embodied impact of diesel (occurring from its extraction and refining) and the impact from fertilizers production. Fine particulate matter formation was also affected mainly by use of diesel, due to incomplete combustion in diesel engines, leading to the exhaustion of solid particles along with the gas emissions. Freshwater ecotoxicity impacts are attributed mainly to the emissions from the plant protection products' application.

3.3.4 Interpretation of LCA results – Apple farming, Spain

The main environmental impact of the Spanish UC on each midpoint impact category is attributed to the use of diesel for farming activities and the application of synthetic fertilizers. The objectives of next year's studies will involve evaluating the potential of the selected CSA practices to reduce this impact in key categories, including global warming, fossil resource scarcity, and ozone formation, through outcomes such as the reduction of diesel use or the production of energy credits. Energy credits can play a crucial role in decreasing diesel use in farm equipment by incentivizing the adoption of renewable energy sources and more efficient technologies.

3.3.5 Life Cycle Cost Analysis (LCC) – Apple farming, Spain

The life cycle costs of the annual apples production cycle for the baseline scenario of the Spanish UC are presented in Figure 15, along with the revenues including subsidies and sale of apples. Only OpEx are taken into account during this production cycle, as only the apple's growth and harvesting are included within the studied system boundaries. Other stages, such as orchard establishment, are excluded and any equipment used is considered to have been depreciated, with only its maintenance costs considered. A significant contribution to the total costs is attributed to the labor costs, reaching up to 4,490 € per ha. The total costs are calculated up to 10,890 € (direct costs: 2,706 €, indirect costs: 8,184 €) whereas the revenues are up to 15,220 €, leading to a sum profit of 4,330 € per ha per year.

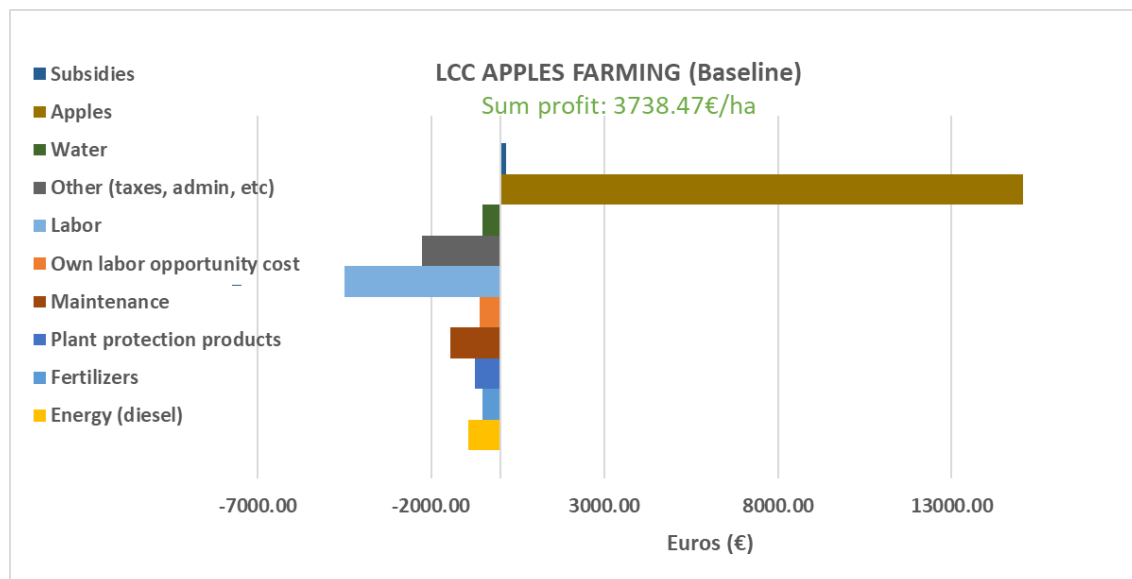


Figure 15: Life Cycle Cost Analysis of the Spanish UC per ha per year, baseline scenario (Positive values correspond to annual revenues, negative values correspond to annual expenses).

3.3.6 Social Life Cycle Impact Assessment (s-LCIA) and interpretation of results – Apple farming, Spain

The production flows and relevant inventory data of the Spanish Baseline scenario were taken from the resulting LCIA shown in previous section 3.3.2. Data inputs and calculated results for the social indicators of the Spanish Baseline scenario are presented in Table 21. Values in bold were values taken directly from the distributed questionnaire, while values with normal fonts were taken directly from the data sources presented in Table 4. Regarding the “Worker hours” activity variable, data for all the parameters was taken from Eora 2019 and ILOstat databases. The Unit labor cost was calculated based on an annual production of 35 tonnes of apples per hectare and an average annual compensation of 15220.41 € per hectare. A further 33% annual working time was assumed (4 months), mainly for harvesting. The hourly labor costs were calculated assuming 4.5 weeks/month. Using the values from the databases, the activity variable “Worker hours” was calculated as follows. The activity variable was used in every indicator and the respective DALYs were calculated. Note that some indicators give combined results (e.g. the 3 wage indicators have combined output as “Fair Salary” - see Table 21 & Figure 16):

$$\text{Unit Labour Costs} = \frac{6253.2}{35000} = 0.1787 \text{ €}$$

and

$$\text{Worker hours} = \frac{0.1787 \text{ €}}{8.6418 \text{ €/h}} = 0.0207 \text{ h}$$

Indicator	Value	Risk level	Calculated DALYs
Children in employment, male	No Data	No Data	67612.06
Children in employment, female	No Data	No Data	10694.00
Children in employment, total	No Data	No Data	10681.17
Frequency of forced labor	2.3	Very Low	14004.11
Good produced by forced labor	No Data	No Data	97.33
Trafficking in persons	1	Very Low	2705.34
Living wage, per month	855	High	-
Minimum wage, per month	0.75	Low	-
Sector average wage, per month	1.38 & 1.83	Very Low	-
Fair Salary	-	-	37357.47
Hours of work per employee, per week	40.2	Low	5764.61
Women in the sectoral labor force	0.92	Very Low	2333.09
Men in the sectoral labor force	1.09	Very Low	8.85
Gender wage gap	1.11%	Very Low	8967.39
Accident rate at workplace, non-fatal	0	Very Low	198.44

Accident rate at workplace, fatal	0	Very Low	75.54
DALYs due to indoor and outdoor air and water pollution	4.57	Very Low	633.44
Presence of sufficient safety measures	Yes	Very Low	8370.15
Workers affected by natural disasters	0.2649%	Very Low	312.50
Social security expenditures	19.19%	Low	57568.08
Evidence of violations of laws & employment regulations	0.1<y<1	Low	3829.92
Trade union density	12.4	Very High	58804.78
Right of Association	2	Low	-
Right of Collective bargaining	2	Low	-
Right to Strike	2	Low	-
Association and Bargaining rights	-	-	1232.32
Presence of anti-competitive behavior or violation of anti-trust & monopoly legislation	0.0461	Very Low	66525.11
Public sector corruption	60	High	72909.07
Active involvement of enterprises in corruption & bribery	4%	Low	11240.48
Membership for social responsibility along supply chain	No	Very High	4299.37
Global Peace Index (Risk of Conflicts)	1.65%	Low	7067.43
Contribution of the sector to economic development	2.96	Low Opportunity	506.28
Value added (total)	-	-	250.24
Public expenditure on education	6.57	Medium	573.99
Adult illiteracy rate (15+ years), male	1	Very Low	58122.06
Adult illiteracy rate (15+ years), female	2	Low	60193.46
Adult illiteracy rate (15+ years), total	1	Very Low	58336.84
Youth illiteracy rate, male	1	Very Low	5911.38
Youth illiteracy rate, female	0	Very Low	5831.13
Youth illiteracy rate, total	0	Very Low	5915.85
Health expenditure, total	10.07%	Low	-
Health expenditure, public	73.30%	Low	-
Health expenditure, out-of-pocket	19.60%	Low	-
Health expenditure, external resources	No Data	No Data	-
Health expenditure	-	-	24994.52
Life expectancy at birth	83	No Risk	9643.61
Violations of mandatory health and safety standards	4E-6	High	-
Level of industrial water use (Total Withdrawal)	18.95%	Low	-
Level of industrial water use (Renewable resources)	4.93%	Medium	-
Industrial water depletion	-	-	2324.57
Extraction of materials per population (Fossil fuels)	0.03	Very Low	9.45
Extraction of materials per population (Ores)	0.28	Very Low	-
Extraction of materials per population (Minerals)	3.24	Low	-
Minerals' consumption	-	-	1457.87
Extraction of materials per population (Biomass)	3.54	Low	-
Extraction of materials per area (Biomass)	332.69	Low	-
Biomass consumption	-	-	68366.09
Certified Environmental Management Systems	No	Very High	3947.12
Presence of indigenous population	Yes	Medium	-
Indigenous Rights Protection Index	4	Low	-
Indigenous rights	-	-	1161.04
Pollution level of the country	35.6	Low	8935.56
Drinking water coverage (urban, rural, total)	98.64% & 99.78%	Very Low	71308.88
Sanitation coverage (urban, rural, total)	100% & 99.90%	No & Very Low	24705.79
Unemployment rate	12.9	Medium	9120.07
International migrant workers in the sector	24%	Very High	14411.66
International migrant stock	12.7	High	701.54
Net migration rate	4.2	Low	9.32
Immigration rate	0.0096	Medium	-
Emigration rate	0.0064	High	-
Asylum seekers rate	2.92E-04	Low	-
Migration flows	-	-	3567.29
GHG Footprints	No Data	No Data	11166.02
Embodied agricultural area footprints	No Data	No Data	160.78
Embodied biodiversity footprints	No Data	No Data	18901.99
Embodied forest area footprints	No Data	No Data	7.84
Embodied water footprints	No Data	No Data	836.05

Table 21: S-LCA Data for the Spanish Baseline scenario of the BEATLES project: Indicator values, associated risk levels and calculated DALYs for 1 year of production (Values in **bold** are data taken from the distributed questionnaire)

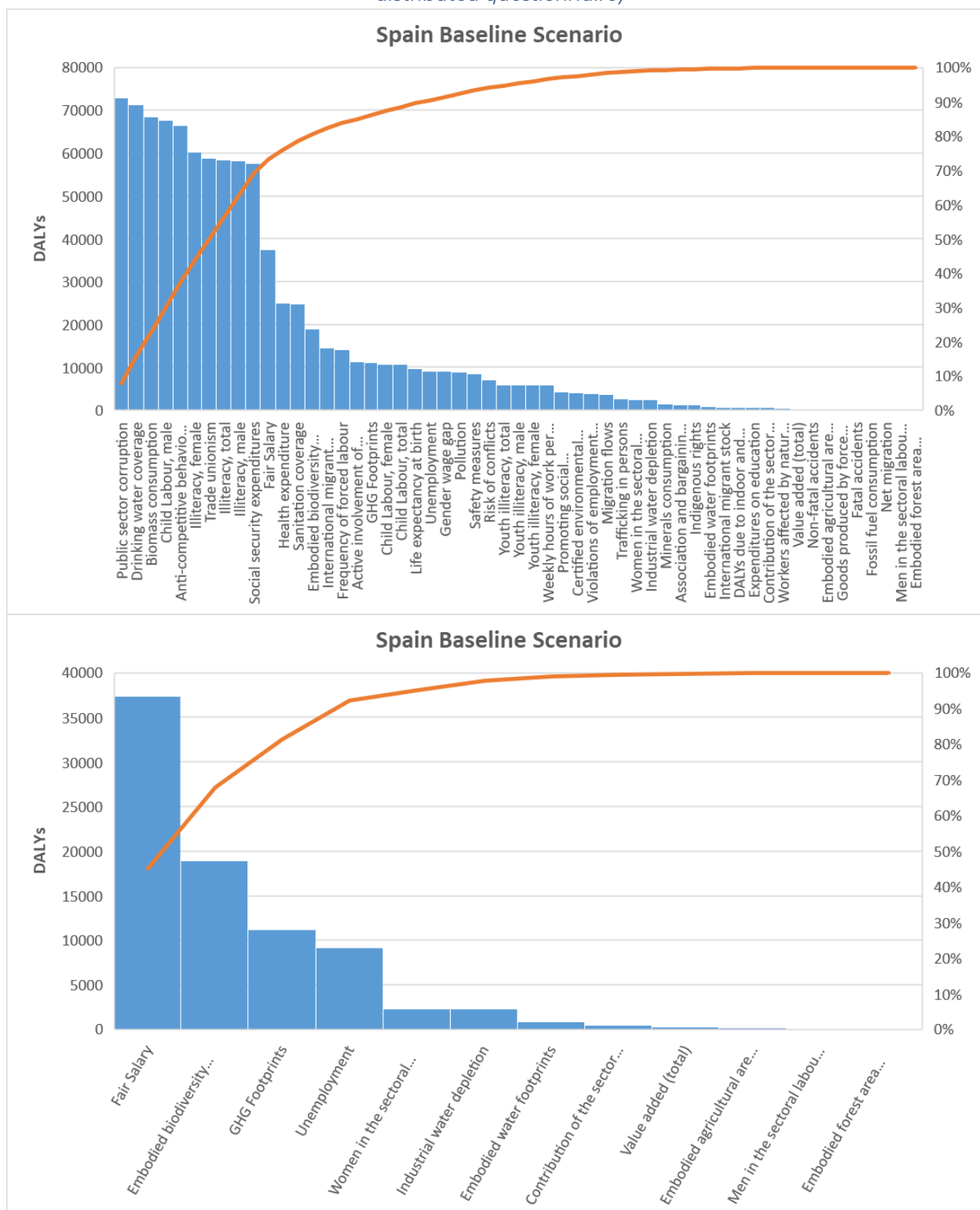


Figure 16: (**Top**) Pareto chart with S-LCA results from the Spanish Baseline scenario of the BEATLES project for 1 year of production showing all evaluated SOCA 2 indicators and (**Bottom**) same Pareto chart simplified to include only the EU CAP-relevant indicators (The orange line is the Pareto line of aggregate percentages of the factors on the X axis)

The S-LCA analysis of the Spanish Baseline scenario resulted in total 924670.340 DALYs. Most of them resulted from 10 factors, namely the Public sector corruption (72909,07 DALYs), followed by

The S-LCA analysis of the Spanish Baseline scenario resulted in total 924670.340 DALYs. Most of them resulted from 10 factors, namely the Public sector corruption (72909,07 DALYs), followed by Drinking water coverage (71308.88 DALYs), Biomass consumption (68366,09 DALYs), Male child labor (67612.06 DALYs), Anti-competitive behavior (66525.10 DALYs), Female illiteracy rate (60193,46 DALYs), Trade unionism (58804.78 DALYs), Total illiteracy rate (58336,84 DALYs), Male illiteracy rate (58122,06 DALYs) and Social security expenditures (57568.08 DALYs). These factors account for ~70% of the total resulting DALYs. On the other hand, the least impactful factors were the Embodied forest area footprints (7.83 DALYs), followed by Men sectoral labor force (8.85 DALYs), Net migration (9.32 DALYs) and Fossil fuel consumption (9.45 DALYs). These contributed <0.005% to the total resulting DALYs.

Focusing on the CAP-relevant indicators that are more in accordance with the BEATLES project (Figure 16 Bottom), the 4 most important factors were the Fair Salary (37357.47 DALYs), followed by Embodied Biodiversity Footprints (18901.99 DALYs), GHG Footprints (11166.02 DALYs) and Unemployment rate (9120.07 DALYs). Judging by the relevant inputs and risk assessments in Table 20, apart maybe from Unemployment rate (medium risk) these high-risk results for the aforementioned indicators were not expected, as the associated risks ranged from No Data-Low (Embodied biodiversity Footprints, GHG Footprints) to very low (Fair Salary). However, since the analysis is conducted on a Life Cycle basis on global scale, there are several upstream flows that contribute to overall risks, and indeed it was found that most of the risks were associated with the flow related to the fertilizer production on global scale, followed by irrigation and production and use of diesel. It is anticipated that a change in production flowcharts and/or the applied activity variables due to an application of a CSA practice might cause a desired reduction to some of these high-risk impacts.

3.4 Use Case Pilot #4: Pig sector, Denmark

3.4.1 Goal and Scope definition – Danish UC (pig farm)

The **goal** of the involved assessments (LCA, LCC and s-LCA) is the evaluation of the environmental, economic and social sustainability of a pig farm that will serve as the Spanish baseline scenario. This scenario represents a conventional pig farm that does not include any of the CSA practices that will be studied in next year activities. This evaluation will serve as a benchmark for the comparison with the alternative scenarios that incorporate the CSA practices.

For the definition of the **scope** of the study, after thorough communication with the Danish UC leader, process flow diagram depicting the baseline scenario (product system) has been developed. The studied UC is briefly outlined, accompanied by flowchart illustrating the process (Fig. 5), and supplemented with data collected from distributed questionnaires.

Product system:

The product system is a dairy farm that does not apply any of the CSA practices that will be studied in the next year's activities. This farm has been studied in this year's activities and will be compared with scenarios that include CSA practices in next year's activities. The main processes along with all the relative flows are presented in Figure 17.

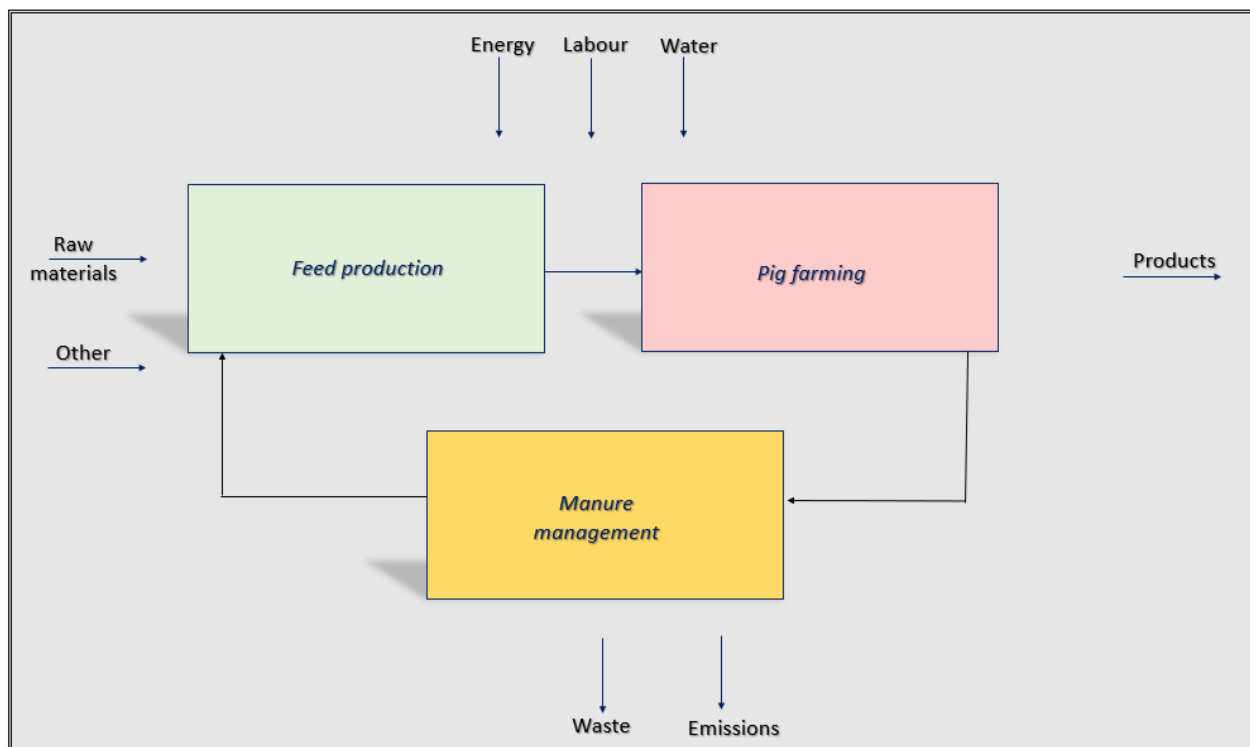


Figure 17: Flowchart of the Danish UC baseline scenario.

Functions of the product system: The main processes that are included within the product system are the following: feed production, pig farming and manure management. The sustainability assessment will consider the overall flows of the entire product system rather than individually for each process.

Functional unit: 1 kg of pig meat growth.

System boundaries: A cradle-to-gate approach has been selected for the sustainability evaluation of the product system, as the effect of the CSA practices that will be studied in the next year's activities is depicted on these stages. More specifically, the boundaries of the system encompass all the stages from the land preparation till the harvesting of the final product.

Allocation procedures: Since there are no multiple products involved, no allocation is needed.

Environmental impact assessment methodology and types of impacts, and interpretation to be performed: ReCiPe 2016 (H, hierarchist) will be used in order to convert the LCI data into a set of environmental impact scores using characterization factors. Detailed description of the method is provided in subsection 2.1.2.

Data requirements: To conduct the LCA analysis, data were gathered through the distribution of questionnaires to relevant stakeholders, supplemented by data from verified databases such as Ecoinvent, Agri-footprint and Agribalyse, which cover the geographical area of the European Union 28 (EU-28). The collected data are based on average production data for Denmark in 2022.

Assumptions/Limitations: The collected data correspond to a farm representative of a conventional pig farm located in Denmark, with a farm area that serves as the minimum requirement for distributing organic manure generated from the entire animal production will be used as the baseline product system. Adhering to legal standards (Nitrates Directive), there's a maximum limit of 170 kg/N per ha from organic sources. The farm engages in the production of piglets and finisher pigs, alongside cultivating wheat (177.5 ha) and barley (100 ha) for in-house feed production. Additionally, oilseed rape (canola) is cultivated across 48 ha, while rye grass is

grown on 18.5 ha, with an additional 26 ha designated for other purposes like extensive permanent grass and fallow land. The stable infrastructure comprises two climate systems for piglets and finisher pigs, featuring partial slatted floors with 50-75% solid floor coverage. None of the CSA practices, that will be studied in the next year's activities are applied in the specific product system.

3.4.2 Life Cycle Inventory (LCI) – Danish UC (pig farm)

The next step after defining the goal and scope of the study is the life cycle data inventory, which links all activities with quantitative data according to the selected functional unit. For the development of the data inventory, appropriate questionnaires were prepared and provided to the UC leader for distribution to the relevant stakeholders (farmers, advisors, etc). Values were estimated based on average production data from example farms in Denmark (2022). However, precise inventory figures fluctuate due to varying requirements for raw materials such as fertilizers and chemicals, which are adjusted annually in collaboration with farm advisors. On average, finisher pigs consume 221.8 feed units per pig, with a feeding plan outlined specifically for this category. While the farm owner's age aligns with the average, salary figures are based on statistics rather than actual farm-specific data. Following data collection, validation and aggregation of these data were performed. Where necessary, supplementary data from appropriate scientific databases (Ecoinvent, Agribalyse, Agri-footprint) or literature sources were used for the establishment of the LCI. The inventory is presented in Table 22, with all flows aggregated using 1 kg of pig meat growth as the Functional Unit.

Parameter	Unit	Value	Data source
INPUTS			
Land use	m ²	2.81	Advisor interview
Fertilizers			
Chemical fertilizer (NS27-4)	kg	0.04	Advisor interview
Manure	kg	10	
Animal Feed			
Wheat grain	kg	1.55	Advisor interview
Barley grain	kg	0.48	
Soybean oil	kg	0.03	
Soymeal	kg	0.47	
Minerals	kg	0.10	
Energy			
Diesel	L	0.028	Average value from literature [12]
Operation			
Housing system, fully-slatted floor	LU	0.012	Advisor interview
Water			
Water from public network	L	3.74	Advisor interview
OUTPUTS			
Pig meat growth	kg	1	Average value from literature [13]
Waste (pig meat not suitable for consumption)	kg	0.04	Average value from literature [14]
Ammonia [Inorganic emissions to air]	kg	1.4	Average value from literature [15]
Carbon dioxide (biotic) [Inorganic emissions to air]	kg	39.3	

Table 22: Life Cycle Inventory of a conventional pig farm – Danish UC, baseline scenario. The values are given per kg of pig meat growth per year.

3.4.3 Environmental Life Cycle Impact Assessment (e-LCIA) – Danish UC (pig farm)

LCA analysis was performed for the baseline scenario based on the data collected from the UC, utilizing the SimaPro 9.6 software. For reference, the results of the impact assessment of a relevant scenario with data available in Agri-footprint database for a Danish pig farm are also presented in Tables 23 & 24.

Impact category	Unit	Baseline pig farm (BEATLES)	Baseline pig farm (Agri-footprint)
Global warming	kg CO ₂ eq	3.80E+00	3.47E+00
Stratospheric ozone depletion	kg CFC11 eq	1.76E-05	2.33E-05
Ionizing radiation	kBq Co-60 eq	1.59E-02	4.35E-02
Ozone formation, Human health	kg NO _x eq	1.44E+00	4.98E-03
Fine particulate matter formation	kg PM _{2.5} eq	9.35E-01	3.77E-03
Ozone formation, Terrestrial ecosystems	kg NO _x eq	2.32E+00	7.71E-03
Terrestrial acidification	kg SO ₂ eq	7.63E+00	1.88E-02
Freshwater eutrophication	kg P eq	4.92E-04	9.76E-04
Marine eutrophication	kg N eq	4.19E-03	4.70E-03
Terrestrial ecotoxicity	kg 1,4-DCB	2.72E-01	4.78E+00
Freshwater ecotoxicity	kg 1,4-DCB	1.76E-03	1.65E-01
Marine ecotoxicity	kg 1,4-DCB	2.62E-03	7.80E-02
Human carcinogenic toxicity	kg 1,4-DCB	4.40E-04	3.35E-02
Human non-carcinogenic toxicity	kg 1,4-DCB	-4.22E-01	7.90E+00
Land use	m ² a crop eq	1.31E+01	4.35E+00
Mineral resource scarcity	kg Cu eq	8.64E-02	3.18E-03
Fossil resource scarcity	kg oil eq	4.48E-01	2.36E-01
Water consumption	m ³	2.38E-01	5.37E-02

Table 23: Results of impact assessment of the Danish UC baseline scenario (based on data collected by UC leader for a conventional pig farm) per 1 kg of pig meat growth per year – midpoint indicators. Results of a relevant scenario based on data obtained from Agri-footprint database are presented in the final column.

Impact category	Unit	Baseline pig farm (BEATLES)	Baseline pig farm (Agri-footprint)
Ecosystems	species.yr	1.93E-06	5.34E-08
Damage to Human health	DALY	5.94E-04	8.15E-06
Resources	USD2013	1.03E-01	8.28E-02

Table 24: Results of impact assessment of the Danish UC baseline scenario (based on data collected by UC leader for a conventional pig farm) per 1 kg of pig meat growth per year – endpoint indicators. Results of a relevant scenario based on data obtained from Agri-footprint database are presented in the final column.

Table 23 lists the annual average impacts per 1 kg of pig meat growth per year for the 18 midpoint impact categories under investigation, based on the methodology followed (ReCiPe 2016, H). The UC farm presents many similarities with the scenario of Agri-footprint in various important categories, including Global Warming, Ozone Depletion, Ionizing Radiation, Freshwater and

Marine Eutrophication and Fossil Resource Scarcity. Any differences in the rest of the midpoint impact categories may be due to variations in the farm conditions. The results of the environmental assessment of the UC scenario will be used in the next year activities as a baseline for comparison with scenarios that include the application of selected CSA practices.

A detailed percentage distribution of the contribution of each agricultural input in the 18 midpoint impact categories is presented in Table 25. The effect of each input in selected midpoint impact categories is also presented in Figure 18.

Impact category	Unit	Housing system	Barley grains	Energy (diesel)	Soybean meal	Soybean oil	Biodegradable waste	Wheat grains	Emissions (pigs)	Emissions (chemical agents)
Global warming	kg CO2 eq	26.06%	3.81%	0.32%	5.18%	0.51%	-0.14%	12.97%	51.29%	0.00%
Stratospheric ozone depletion	kg CFC11 eq	1.50%	13.61%	0.09%	13.21%	1.31%	-0.01%	54.16%	16.12%	0.00%
Ionizing radiation	kBq Co-60 eq	86.81%	2.15%	0.22%	4.21%	0.42%	-0.40%	6.60%	0.00%	0.00%
Ozone formation, Human health	kg NOx eq	91.53%	1.19%	0.21%	2.45%	0.24%	0.80%	3.56%	0.02%	0.00%
Fine particulate matter formation	kg PM2.5 eq	0.03%	0.02%	0.00%	0.03%	0.00%	0.00%	0.08%	99.83%	0.00%
Ozone formation, Terrestrial ecosystems	kg NOx eq	91.59%	1.17%	0.21%	2.43%	0.24%	0.81%	3.53%	0.02%	0.00%
Terrestrial acidification	kg SO2 eq	0.01%	0.01%	0.00%	0.01%	0.00%	0.00%	0.06%	99.90%	0.00%
Freshwater eutrophication	kg P eq	0.83%	15.67%	0.08%	25.60%	2.54%	0.00%	55.27%	0.00%	0.00%
Marine eutrophication	kg N eq	0.65%	11.66%	0.05%	18.10%	1.79%	0.00%	67.74%	0.00%	0.00%
Terrestrial ecotoxicity	kg 1,4-DCB	86.17%	1.83%	1.22%	3.45%	0.34%	-0.52%	7.52%	0.00%	0.00%

Table 25: Percentage contribution of each flow in the various midpoint indicators – Danish UC, baseline scenario.

Impact category	Unit	Housing system	Barley grains	Energy (diesel)	Soybean meal	Soybean oil	Biodegradable waste	Wheat grains	Emissions (pigs)	Emissions (chemical agents)
Freshwater ecotoxicity	kg 1,4-DCB	3.35%	21.35%	0.85%	1.44%	0.14%	-0.01%	72.88%	0.00%	0.00%
Marine ecotoxicity	kg 1,4-DCB	7.26%	20.23%	1.73%	2.86%	0.28%	-0.04%	67.68%	0.00%	0.00%
Human carcinogenic toxicity	kg 1,4-DCB	33.79%	8.21%	4.74%	27.21%	2.68%	-0.20%	23.58%	0.00%	0.00%
Human non-carcinogenic toxicity	kg 1,4-DCB	0.93%	-7.54%	-1.85%	122.83%	12.16%	0.02%	-26.56%	0.00%	0.00%
Land use	m ² a crop eq	0.63%	7.78%	0.05%	10.75%	1.06%	0.00%	21.50%	0.00%	58.24%
Mineral resource scarcity	kg Cu eq	2.41%	21.29%	0.06%	40.84%	4.04%	0.02%	31.35%	0.00%	0.00%
Fossil resource scarcity	kg oil eq	58.07%	6.19%	5.83%	10.12%	1.00%	-0.41%	19.21%	0.00%	0.00%
Water consumption	m ³	4.92%	3.81%	0.05%	63.06%	6.26%	0.05%	21.86%	0.00%	0.00%

Table 25: Percentage contribution of each flow in the various midpoint indicators – Danish UC, baseline scenario (continued).

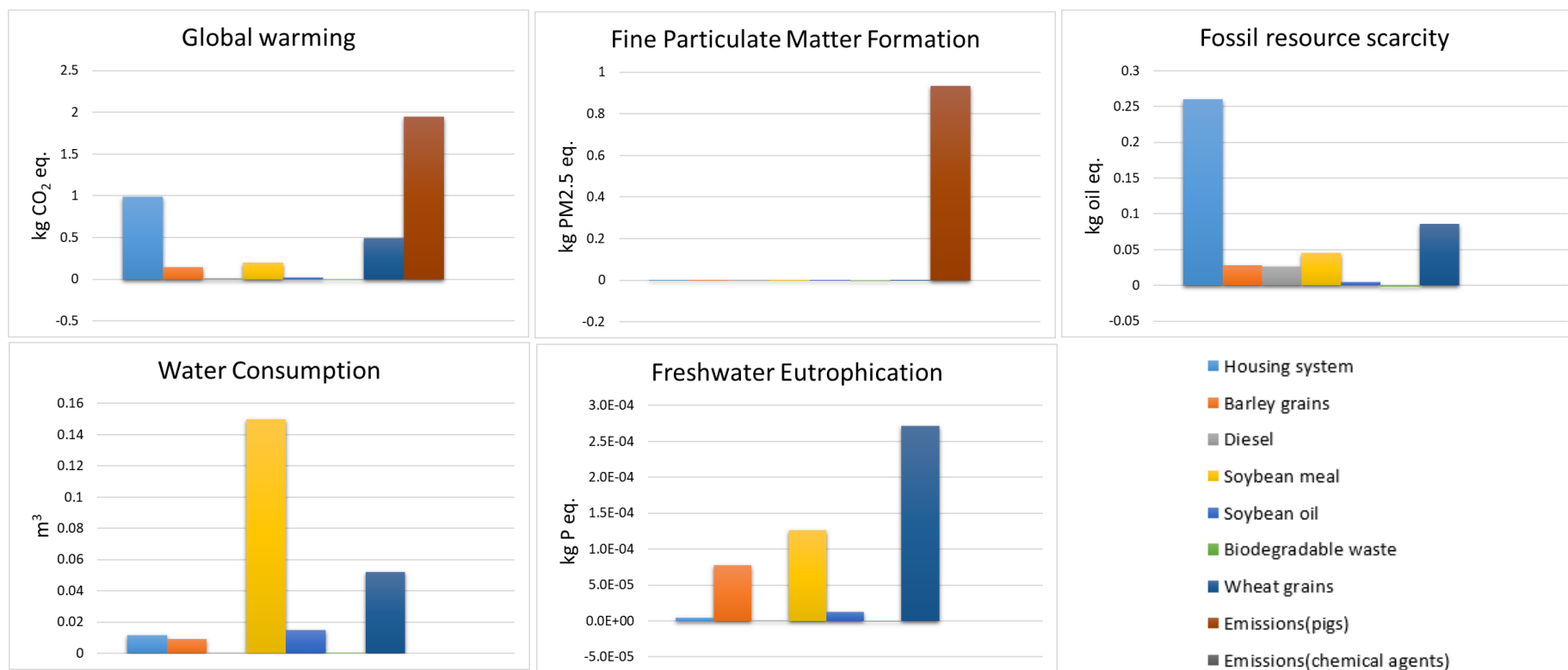


Figure 18: Contributing processes to the midpoint impacts per 1 kg of pig meat growth per year for the baseline scenario – Danish UC.

By analyzing the contributions of pig farming to each impact category for all inputs used, it can be observed that the housing system and the emissions from pig farming/fattening are responsible for the highest impacts in many cases. Pig fattening contributed to global warming at a percentage more than 50%, followed by the housing system contribution (26%). The production of feed also presented contribution to the global warming, reaching up to 22% (barley, soybean and wheat production). The main impact on fossil resource scarcity was observed, as expected, by the energy consumption required in the housing system, reaching up to 0.26 kg oil eq. The feed production had the main effect on water consumption, due to irrigation needs of the cultivars, as well as to water eutrophication, due to the use of pesticides and fertilizers.

3.4.4 Interpretation of LCA results – Danish UC (pig farm)

The main environmental impact of the Danish UC on each midpoint impact category is attributed to the energy needs of the housing system and the emissions of pig fattening and secondary to the pig feed production. The objectives of next year's studies will involve evaluating the potential of the selected CSA practices to reduce this impact in key categories, including global warming, fossil resource scarcity, ozone formation, and water or marine ecotoxicity and eutrophication, through outcomes such as energy credits, decrease of emissions from manure management or the reduction of energy consumption.

3.4.5 Life Cycle Cost Analysis (LCC) – Danish UC (pig farm)

For the calculation of the annual life cycle costs of the pig farm (Danish UC, baseline scenario), only OpEx were taken into account as any equipment, land, building or other CapEx are considered to have been depreciated and only maintenance costs are taken into account. In Figure 19 the expenditures are presented, along with the revenues including subsidies and sale of pigs. The highest OpEx is the purchase/production of feed, reaching up to 0.78€/kg of pig meat growth. The revenues include 1.61€/kg of pig meat growth from pigs' sale and 0.07€/kg of pig meat growth from the provided subsidies. The sum profit per kg of pig meat growth is calculated up to 0.50€/kg and the total annual sum profit in the specific farm reaches up to 691,817€.

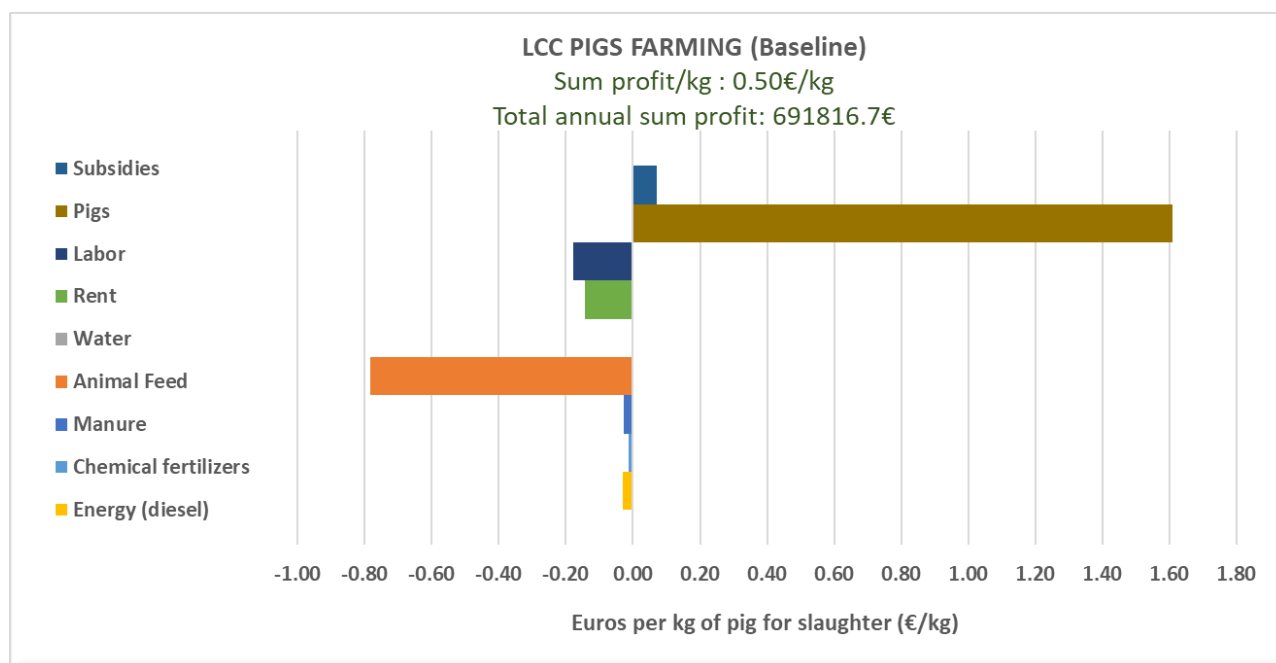


Figure 19: Life Cycle Cost Analysis of the Danish UC, baseline scenario (Positive values correspond to annual revenues, negative values correspond to annual expenses).

3.4.6 Social Life Cycle Impact Assessment (s-LCIA) and interpretation of results – Danish UC (pig farm)

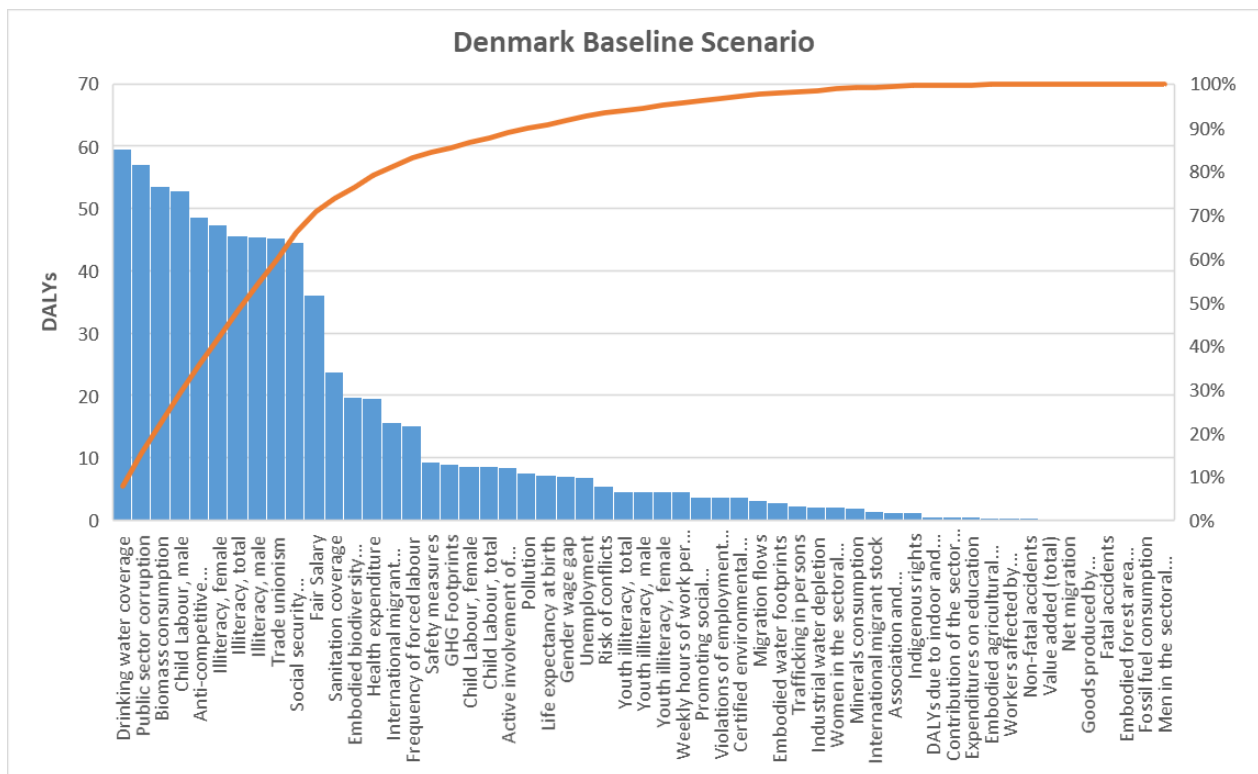
The production flows and relevant inventory data of the Danish Baseline scenario were taken from the resulting LCIA shown in previous section 3.4.2. Data inputs and calculated results for the social indicators of the Danish Baseline scenario are presented in Table 26. Values in bold were values taken directly from the distributed questionnaire, while values with normal fonts were taken directly from the data sources presented in Table 4. Regarding the “Worker hours” activity variable, the Unit labor cost was calculated based on an annual production of 1378.68 tonnes of pig meat and an average annual compensation of 35131.43 €. The hourly labor costs were calculated assuming 4.5 weeks/month. The activity variable was used in every indicator and the respective DALYs were calculated. Note that some indicators give combined results (e.g. the 3 wage indicators have combined output as “Fair Salary” - see Table 26 & Figure 20):

$$\text{Unit Labour Costs} = \frac{35131.43}{1378680.22} = 0.0255 \text{ €} \quad \text{and} \quad \text{Worker hours} = \frac{0.0255 \text{ €}}{17.5833 \text{ €/h}} = 0.0014 \text{ h}$$

Indicator	Value	Risk level	Calculated DALYs
Children in employment, male	No Data	No Data	52.771
Children in employment, female	No Data	No Data	8.648
Children in employment, total	No Data	No Data	8.638
Frequency of forced labor	0.6	Very Low	15.104
Good produced by forced labor	No Data	No Data	0.115
Trafficking in persons	1	Very Low	2.210
Living wage, per month	No Data	No Data	-
Minimum wage, per month	No Data	No Data	-
Sector average wage, per month	No Data	No Data	-
Fair Salary	-	-	36.133
Hours of work per employee, per week	37	Medium	4.494
Women in the sectoral labor force	0.29	High	2.061
Men in the sectoral labor force	0.71	Low	0.008
Gender wage gap	7%	Low	7.011
Accident rate at workplace, non-fatal	0	Very Low	0.283
Accident rate at workplace, fatal	0	Very Low	0.062
DALYs due to indoor and outdoor air and water pollution	5.34	Low	0.495
Presence of sufficient safety measures	Yes	Very Low	9.417
Workers affected by natural disasters	0.0034%	Very Low	0.304
Social security expenditures	22.98%	Very Low	44.651
Evidence of violations of laws & employment regulations	0.1<y<1	Low	3.740
Trade union density	67.0	Low	45.347
Right of Association	2	Low	-
Right of Collective bargaining	2	Low	-
Right to Strike	2	Low	-
Association and Bargaining rights	-	-	1.241
Presence of anti-competitive behavior or violation of anti-trust & monopoly legislation	0.0461	Very Low	48.622
Public sector corruption	90	Very Low	57.110
Active involvement of enterprises in corruption & bribery	4%	Low	8.524
Membership for social responsibility along supply chain	Some	Medium	3.753
Global Piece Index (Risk of Conflicts)	1.31%	Very Low	5.540
Contribution of the sector to economic development	1.64	Low Opportunity	0.472
Value added (total)	-	-	0.245
Public expenditure on education	9.52	Low	0.451
Adult illiteracy rate (15+ years), male	0	Very Low	45.418
Adult illiteracy rate (15+ years), female	1	Very Low	47.310
Adult illiteracy rate (15+ years), total	1	Very Low	45.570
Youth illiteracy rate, male	0	Very Low	4.571
Youth illiteracy rate, female	0	Very Low	4.549
Youth illiteracy rate, total	0	Very Low	4.580
Health expenditure, total	10.50%	Low	-
Health expenditure, public	84.90%	Very Low	-
Health expenditure, out-of-pocket	12.80%	Low	-

Health expenditure, external resources	0%	Very Low	-
Health expenditure	-	-	19.551
Life expectancy at birth	81	No Risk	7.267
Violations of mandatory health and safety standards	136E-7	Very High	-
Level of industrial water use (Total Withdrawal)	No Data	No Data	-
Level of industrial water use (Renewable resources)	No Data	No Data	-
Industrial water depletion	-	-	2.170
Extraction of materials per population (Fossil fuels)	0.78	Very Low	0.009
Extraction of materials per population (Ores)	0.00	Very Low	-
Extraction of materials per population (Minerals)	9.90	Medium	-
Minerals' consumption	-	-	2.023
Extraction of materials per population (Biomass)	5.63	Medium	-
Extraction of materials per area (Biomass)	777.77	High	-
Biomass consumption	-	-	53.477
Certified Environmental Management Systems	No	Very High	3.712
Presence of indigenous population	Yes	Medium	-
Indigenous Rights Protection Index	5	Very Low	-
Indigenous rights	-	-	1.193
Pollution level of the country	21.9	Low	7.572
Drinking water coverage (urban, rural, total)	100%	No Risk	59.630
Sanitation coverage (urban, rural, total)	99.60%	Very Low	23.717
Unemployment rate	4.4	Low	6.868
International migrant workers in the sector	50%	Very High	15.642
International migrant stock	10.1	High	1.464
Net migration rate	2.7	Low	0.225
Immigration rate	0.00797	Low	-
Emigration rate	0.00531	Medium	-
Asylum seekers rate	3.89E-05	Very Low	-
Migration flows	-	-	3.247
GHG Footprints		Low	8.921
Embodied agricultural area footprints		Medium	0.424
Embodied biodiversity footprints	No Data	No Data	19.767
Embodied forest area footprints	No Data	No Data	0.015
Embodied water footprints	No Data	No Data	2.770

Table 26: S-LCA Data for the Danish Baseline scenario of the BEATLES project: Indicator values, associated risk levels and calculated DALYs for 1 year of production (Values in bold are data taken from the distributed questionnaire)



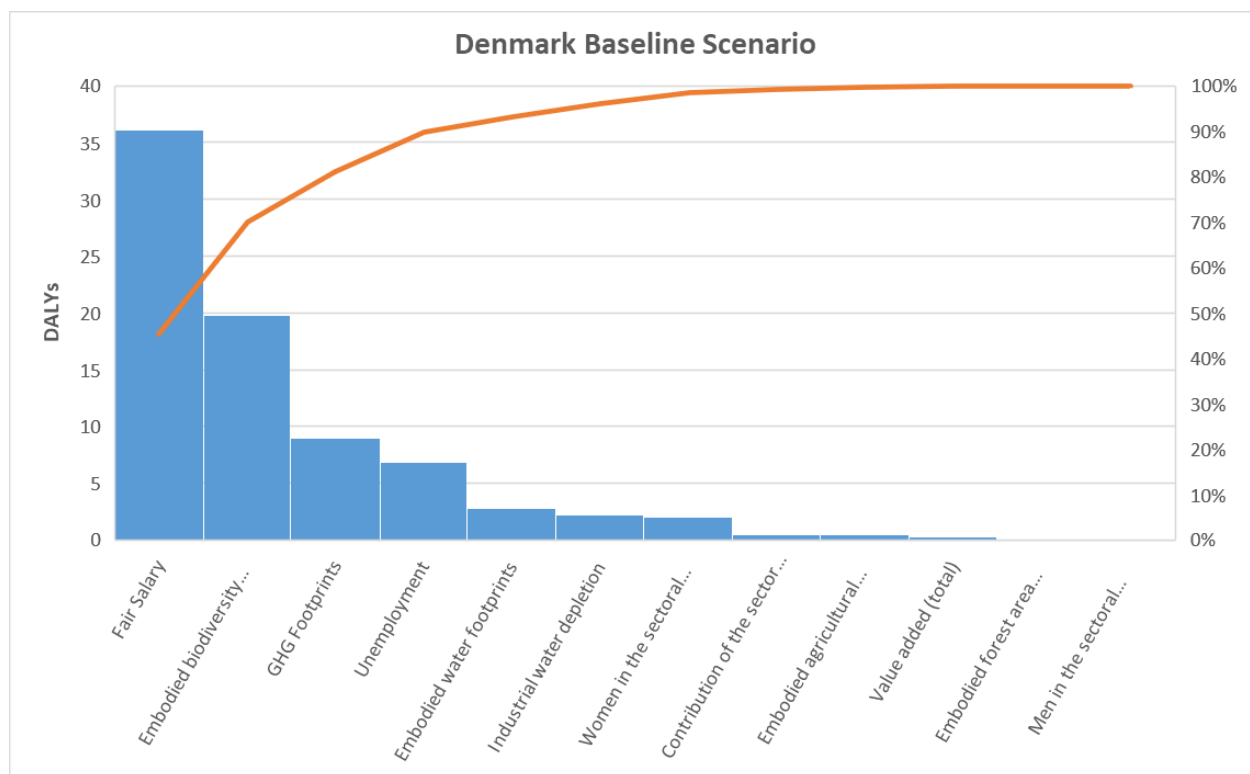


Figure 20: **(Top)** Pareto chart with S-LCA results from the Danish Baseline scenario of the BEATLES project for 1 year of production showing all evaluated SOCA 2 indicators and **(Bottom)** same Pareto chart simplified to include only the EU CAP-relevant indicators (The orange line is the Pareto line of aggregate percentages of the factors on the X axis)

The S-LCA analysis of the Danish Baseline scenario resulted in total 759.11 DALYs. Most of them resulted from 11 factors, namely the Drinking water coverage (59.63 DALYs), followed by Public sector corruption (57.11 DALYs), Biomass consumption (53.48 DALYs), Male child labor (52.77 DALYs), Anti-competitive behavior (48.62 DALYs), Female illiteracy rate (47.31 DALYs), Total illiteracy rate (45.57 DALYs), Male illiteracy rate (45.42 DALYs), Trade unionism (45.35 DALYs), Social security expenditures (44.65 DALYs) and Fair salary (36.13 DALYs). These factors account for ~70% of the total resulting DALYs. On the other hand, the least impactful factors were the Men sectoral labor force (0.008 DALYs), followed by Fossil fuel consumption (0.009 DALYs) and Embodied forest area footprints (0.015 DALYs). These contributed <0.005% to the total resulting DALYs.

Focusing on the CAP-relevant indicators that are more in accordance with the BEATLES project (Figure 20 Bottom), the 4 most important factors were the Fair Salary (36.13 DALYs), followed by Embodied Biodiversity Footprints (19.77 DALYs), GHG Footprints (8.92 DALYs) and Unemployment rate (6.87 DALYs). Judging by the relevant inputs and risk assessments in Table 25, these high-risk results for the aforementioned indicators were not expected, as the associated risks with all 4 indicators were assigned as No Data-Low. However, since the analysis is conducted on a Life Cycle basis on global scale, there are several upstream flows that contribute to overall risks, and indeed it was found that most of the risks were associated with the flow related to the production of wheat seed for sowing on global scale, followed by animal housing operation on global scale (more specifically to the required low voltage electricity). It is anticipated that a change in production flowcharts and/or the applied activity variables due to an application of a CSA practice might cause a desired reduction to some of these high-risk impacts.

3.5 Use Case Pilot #5: Onions & Potatoes (Vegetables), The Netherlands

3.5.1 Goal and Scope definition – Dutch UC (onions & potatoes cultivation)

The **goal** of the assessments undertaken (LCA, LCC and s-LCA) is to conduct an environmental, economic, and social evaluation of the Dutch UC baseline scenario. This scenario represents a conventional farm that does not include any of the CSA practices that will be studied in next year activities. This evaluation will serve as a benchmark for the comparison with the alternative scenarios that incorporate the CSA practices.

For the definition of the **scope** of the study, after thorough communication with the Dutch UC leader, process flow diagram depicting the baseline scenario (product system) has been developed. The studied UC is briefly outlined, accompanied by flowchart illustrating the process (Fig. 4), and supplemented with data collected from distributed questionnaires. The main processes along with all the relative flows are presented in Figure 21.

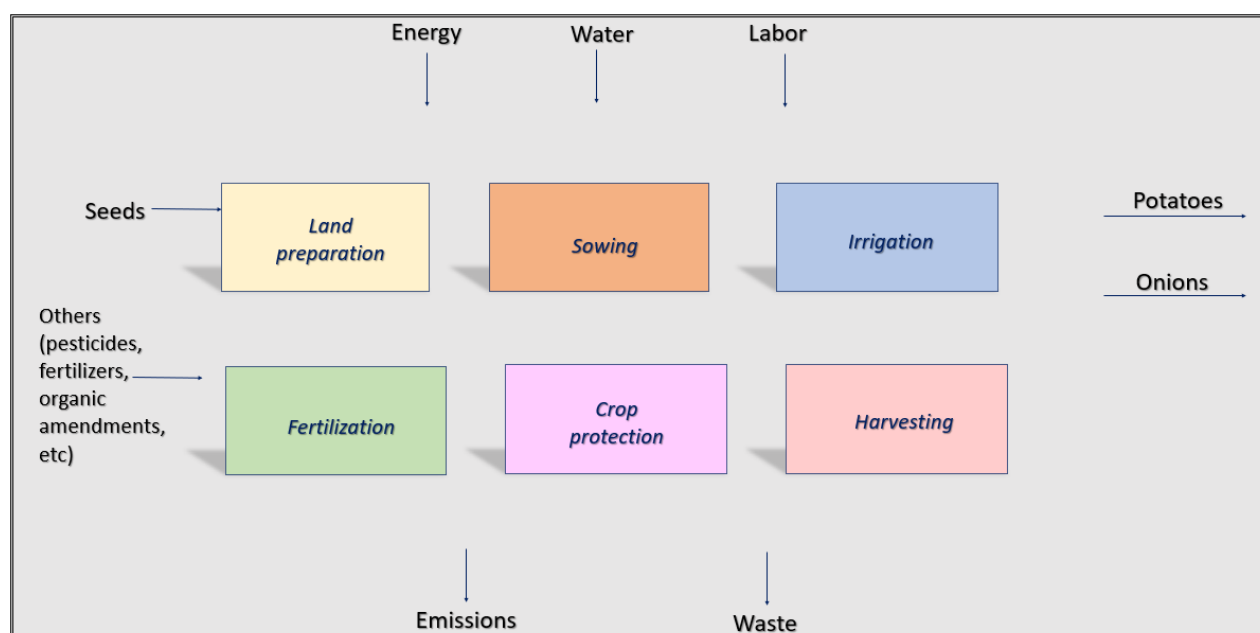


Figure 21: Flowchart of the Dutch UC baseline scenario.

Functions of the product system: The main processes that are included within the product system are the following: land preparation, sowing, irrigation, fertilization, crop protection and harvesting of potatoes or onions. The sustainability assessment will consider the overall flows of the entire product system rather than individually for each process. Two different scenarios were studied for the specific UC: one for the production of potatoes and one for the production of onions.

Functional unit: 1 ha of cultivated land.

System boundaries: A cradle-to-gate approach has been selected for the sustainability evaluation of the product system, as the effect of the CSA practices that will be studied in the next year's activities is depicted on these stages. More specifically, the boundaries of the system encompass all the stages from the land preparation till the harvesting of the final product.

Allocation procedures: Since there are no multiple products involved, no allocation is needed.

Environmental impact assessment methodology and types of impacts, and interpretation to be performed: ReCiPe 2016 (H, hierarchist) will be used in order to convert the LCI data into a set of environmental impact scores using characterization factors. Detailed description of the method is provided in subsection 2.1.2.

Data requirements: To conduct the LCA analysis, data were gathered through the distribution of questionnaires to relevant stakeholders, supplemented by data from verified databases such as Ecoinvent, Agri-footprint and Agribalyse, which cover the geographical area of the European Union 28 (EU-28). The collected data are based on average data for the Netherlands (source: KWIN).

Assumptions/Limitations: The collected data correspond to a farm representative of conventional onion and potato farms in the Southwest of the Netherlands, with focus on a clay soil.

3.5.2 Life Cycle Inventory (LCI) – Dutch UC (onions & potatoes cultivation)

The next step after defining the goal and scope of the study is the life cycle data inventory, which links all activities with quantitative data according to the selected functional unit. For the development of the data inventory, appropriate questionnaires were prepared and provided to the UC leader for distribution to the relevant stakeholders (farmers, advisors, etc). Following data collection, validation and aggregation of these data were performed. Where necessary, supplementary data from appropriate databases (Ecoinvent, Agribalyse, Agri-footprint) or literature sources were used. The inventory is presented in Tables 27-28, with all flows aggregated using 1 ha of cultivated land as the Functional Unit.

The estimation of the initial emission distribution fractions of the applied chemical agents (fungicides, herbicides and insecticides) was based on emission modelling for pesticides provided in literature [10]. More specifically, the emissions to soil, water and air were estimated based on the percentage of the active compound per case and the appropriate coefficients provided for the category of roots, tubers, and bulbs.

Parameter	Unit	Value	Data source
INPUTS			
Land use	ha	1	
Raw materials			
Potato seeds	kg	2700	Average value from literature (KWIN)
Fertilizers			
KAS 27% N	kg N	250	Average value from literature (KWIN)
Tripelsuper 43-45% P2O5	kg P2O5	40	
Kaliumchloride 60% K2O	kg K2O	180	
Fungicides			
Mandipropamid	L	3.60	Average value from literature (KWIN)
Fluopicolide, propamocarb	L	6.40	
Cyazofamid	L	1.50	
Difenoconazool	L	1.50	
Herbicides			
Metribuzin	l	0.5	

Prosulfocarb	L	5	Average value from literature (KWIN)
Pyraflufen-ethyl	L	0.80	
Carfentrazon-ethyl	L	0.50	
Clomazone	L	0.25	
Insecticides			
Lambda-cyhalothrin	L	0.05	Average value from literature (KWIN)
Sulfoxaflor	L	0.20	
Oils			
Mineral oil	L	0.20	Average value from literature (KWIN)
Orange oil (99.91%)	L	19.28	
Energy			
Diesel	L	284	Average value from literature (KWIN)
Electricity	kWh	747	
OUTPUTS			
Potatoes	kg	48200	Average value from literature (KWIN)
Pesticides [Emissions to agricultural soil]	g	10.38	Literature [10]
Pesticides [Emissions to air]	g	2.44	
Pesticides [Emissions to fresh water]	g	3.34E-04	
Mineral oil [Emissions to fresh water]	mL	0.207	
Mineral oil [Emissions to air]	mL	1636.32	
Mineral oil [Emissions to agricultural soil]	mL	8030.61	

Table 27: Life Cycle Inventory of a conventional potatoes' cultivation farm – Dutch UC, baseline scenario. The values are given per ha per year.

Parameter	Unit	Value	Data source
INPUTS			
Land use	ha	1	
Raw materials			
Onion seeds	units	3.8	Average value from literature (KWIN)
Fertilizers			
KAS 27% N	kg N	170	Average value from literature (KWIN)
Tripelsuper 43-45% P2O5	kg P2O5	40	
Kaliumchloride 60% K2O	kg K2O	180	
Fungicides			
Benthiavalicarb-isopropyl, oxathiapiproline	L	1.5	Average value from literature (KWIN)
Fluoxastrobine, prothioconazool	L	1.25	
Kresoxim-methyl	L	0.80	
Fluopyram, tebuconazool	L	0.50	
Herbicides			
Pendimethalin	L	2	Average value from literature (KWIN)
Fluroxypyr-meptyl	L	0.36	
Izoxaben	L	0.20	
Prosulfocarb	L	5	
Pyridaat	L	1.50	

S-metolachloor		0.75	
Glyfosaat		1.30	
Dimethenamide-P		2	
Insecticides			
Deltamethrin	L	0.60	Average value from literature (KWIN)
Cyantraniliprole	L	0.75	
Others			
Growth regulator	kg	3.75	Average value from literature (KWIN)
Water			
Water from public network	L	2.88E05	Average value from literature (KWIN)
Energy			
Diesel	L	251	Average value from literature (KWIN)
Electricity	kWh	1600	
OUTPUTS			
Onions	kg	50000	Average value from literature (KWIN)
Pesticides [Emissions to agricultural soil]	g	2.22	Literature [10]
Pesticides [Emissions to air]	g	15.23	
Pesticides [Emissions to fresh water]	g	3.29E-04	

Table 28: Life Cycle Inventory of a conventional onion cultivation farm – Dutch UC, baseline scenario. The values are given per ha per year.

3.5.3 Environmental Life Cycle Impact Assessment (e-LCIA) – Dutch UC (onions & potatoes cultivation)

LCA analysis was performed for the baseline scenario based on the data collected from the UC, utilizing the SimaPro 9.6 software. For reference, the results of the impact assessment of relevant scenarios with data available in Ecoinvent database for potato and onion production in the Netherlands are also presented in Tables 29-32.

Impact category	Unit	Baseline onion farm (BEATLES)	Baseline onion farm (Ecoinvent)
Global warming	kg CO ₂ eq	5.08E-02	1.29E-01
Stratospheric ozone depletion	kg CFC11 eq	7.31E-07	2.54E-04
Ionizing radiation	kBq Co-60 eq	1.92E-04	4.91E-04
Ozone formation, Human health	kg NO _x eq	1.86E-02	2.01E-01
Fine particulate matter formation	kg PM _{2.5} eq	5.05E-05	7.92E-07
Ozone formation, Terrestrial ecosystems	kg NO _x eq	2.99E-02	1.26E-01
Terrestrial acidification	kg SO ₂ eq	2.49E-04	2.76E-02
Freshwater eutrophication	kg P eq	3.24E-05	6.85E-04
Marine eutrophication	kg N eq	4.54E-04	2.80E-03
Terrestrial ecotoxicity	kg 1,4-DCB	3.70E-01	2.38E-02

Freshwater ecotoxicity	kg 1,4-DCB	4.70E-03	2.99E-04
Marine ecotoxicity	kg 1,4-DCB	6.33E-03	4.38E-03
Human carcinogenic toxicity	kg 1,4-DCB	3.97E-05	1.35E-03
Human non-carcinogenic toxicity	kg 1,4-DCB	-6.36E-02	2.40E-05
Land use	m ² a crop eq	1.52E-03	6.42E-01
Mineral resource scarcity	kg Cu eq	5.79E-05	4.90E-04
Fossil resource scarcity	kg oil eq	1.91E-02	1.35E-03
Water consumption	m ³	7.15E-05	6.69E-04

Table 29: Results of impact assessment of the Dutch UC baseline scenario for onions cultivation (based on data collected by UC leader for a conventional onion farm) per ha per year – midpoint indicators. Results of a relevant scenario based on data obtained from Ecoinvent database are presented in the final column.

Impact category	Unit	Baseline onion farm (BEATLES)	Baseline onion farm (Ecoinvent)
Ecosystems	species.yr	4.12E-09	2.94E-09
Damage to Human health	DALY	1.10E-07	4.08E-07
Resources	USD2013	6.76E-03	1.16E-02

Table 30: Results of impact assessment of the Dutch UC baseline scenario for onions cultivation (based on data collected by UC leader for a conventional onion farm) per ha per year – endpoint indicators. Results of a relevant scenario based on data obtained from Ecoinvent database are presented in the final column.

Impact category	Unit	Baseline potato farm (BEATLES)	Baseline potato farm (Ecoinvent)
Global warming	kg CO ₂ eq	1.66E-02	-1.36E-01
Stratospheric ozone depletion	kg CFC11 eq	2.90E-07	1.57E-06
Ionizing radiation	kBq Co-60 eq	1.19E-04	6.59E-04
Ozone formation, Human health	kg NO _x eq	1.15E-02	9.59E-02
Fine particulate matter formation	kg PM _{2.5} eq	5.40E-05	1.68E-04
Ozone formation, Terrestrial ecosystems	kg NO _x eq	1.86E-02	1.55E-01
Terrestrial acidification	kg SO ₂ eq	2.32E-04	9.67E-04
Freshwater eutrophication	kg P eq	6.87E-07	2.22E-04
Marine eutrophication	kg N eq	1.44E-05	6.45E-04
Terrestrial ecotoxicity	kg 1,4-DCB	4.80E-01	5.88E-01
Freshwater ecotoxicity	kg 1,4-DCB	1.95E-03	2.78E-02
Marine ecotoxicity	kg 1,4-DCB	1.65E-02	6.13E-03
Human carcinogenic toxicity	kg 1,4-DCB	1.22E-05	2.05E-04
Human non-carcinogenic toxicity	kg 1,4-DCB	5.67E-02	2.47E-01
Land use	m ² a crop eq	6.49E-03	2.02E-01
Mineral resource scarcity	kg Cu eq	1.30E-03	2.76E-03
Fossil resource scarcity	kg oil eq	1.65E-02	7.84E-02
Water consumption	m ³	5.97E-05	7.90E-02

Table 31: Results of impact assessment of the Dutch UC baseline scenario for potatoes cultivation (based on data collected by UC leader for a conventional potato farm) per ha per year – midpoint indicators. Results of a relevant scenario based on data obtained from Ecoinvent database are presented in the final column.

Impact category	Unit	Baseline potato farm (BEATLES)	Baseline potato farm (Ecoinvent)
Ecosystems	species.yr	2.64E-09	2.32E-08
Damage to Human health	DALY	1.03E-07	4.59E-07
Resources	USD2013	6.09E-03	2.95E-02

Table 32: Results of impact assessment of the Dutch UC baseline scenario for potatoes cultivation (based on data collected by UC leader for a conventional potato farm) per ha per year – endpoint indicators. Results of a relevant scenario based on data obtained from Ecoinvent database are presented in the final column.

Tables 29 & 31 list the annual average impacts per cultivated ha for the 18 midpoint impact categories under investigation, based on the methodology followed (ReCiPe 2016, H). The UC farms present some similarities with the scenarios of Ecoinvent in various midpoint indicators; any differences in the midpoint impact categories, may be due to differences in the application of fertilizers and plant protection products, the machine utilization or the needs in irrigation. The results of the environmental assessment of the UC scenario will be used in the next year activities as a baseline for comparison with scenarios that include the application of selected CSA practices.

A detailed percentage distribution of the contribution of each agricultural input in the 18 midpoint impact categories is presented in Tables 33 & 34. The effect of each input in selected midpoint impact categories is also presented in Figures 22 & 23.

Impact category	Unit	Onion seeds production	Energy (Electricity)	Plant protection products	Fertilizers	Energy (Diesel)	Emissions (chemical agents)
Global warming	kg CO2 eq	0.00%	37.04%	7.11%	15.85%	7.68%	32.31%
Stratospheric ozone depletion	kg CFC11 eq	0.00%	0.47%	0.98%	15.90%	0.25%	82.40%
Ionizing radiation	kBq Co-60 eq	0.00%	86.39%	8.46%	1.59%	3.55%	0.00%
Ozone formation, Human health	kg NOx eq	0.00%	83.33%	9.97%	1.47%	5.23%	0.00%
Fine particulate matter formation	kg PM2.5 eq	0.00%	8.42%	4.95%	46.61%	7.92%	32.09%
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.00%	83.34%	9.98%	1.46%	5.22%	0.00%
Terrestrial acidification	kg SO2 eq	0.00%	5.39%	3.20%	33.02%	5.35%	53.05%
Freshwater eutrophication	kg P eq	0.00%	0.13%	0.10%	54.62%	0.10%	45.05%
Marine eutrophication	kg N eq	0.00%	0.08%	0.02%	0.01%	0.03%	99.86%
Terrestrial ecotoxicity	kg 1,4-DCB	0.00%	0.47%	0.16%	0.47%	0.22%	98.68%
Freshwater ecotoxicity	kg 1,4-DCB	0.00%	0.01%	0.01%	0.63%	0.08%	99.25%
Marine ecotoxicity	kg 1,4-DCB	0.00%	0.03%	0.03%	0.62%	0.19%	99.12%
Human carcinogenic toxicity	kg 1,4-DCB	0.00%	11.86%	4.88%	26.21%	14.25%	42.79%
Human non-carcinogenic toxicity	kg 1,4-DCB	0.00%	-0.18%	-0.19%	-5.01%	-2.73%	108.11%
Land use	m ² a crop eq	0.00%	52.99%	6.36%	1.04%	39.61%	0.00%
Mineral resource scarcity	kg Cu eq	0.00%	19.86%	5.34%	64.93%	9.88%	0.00%
Fossil resource scarcity	kg oil eq	0.00%	29.66%	8.60%	18.16%	43.58%	0.00%
Water consumption	m ³	0.00%	49.93%	34.42%	0.96%	14.69%	0.00%

Table 33: Percentage contribution of each flow in the various midpoint indicators – Dutch UC, baseline scenario (onions).

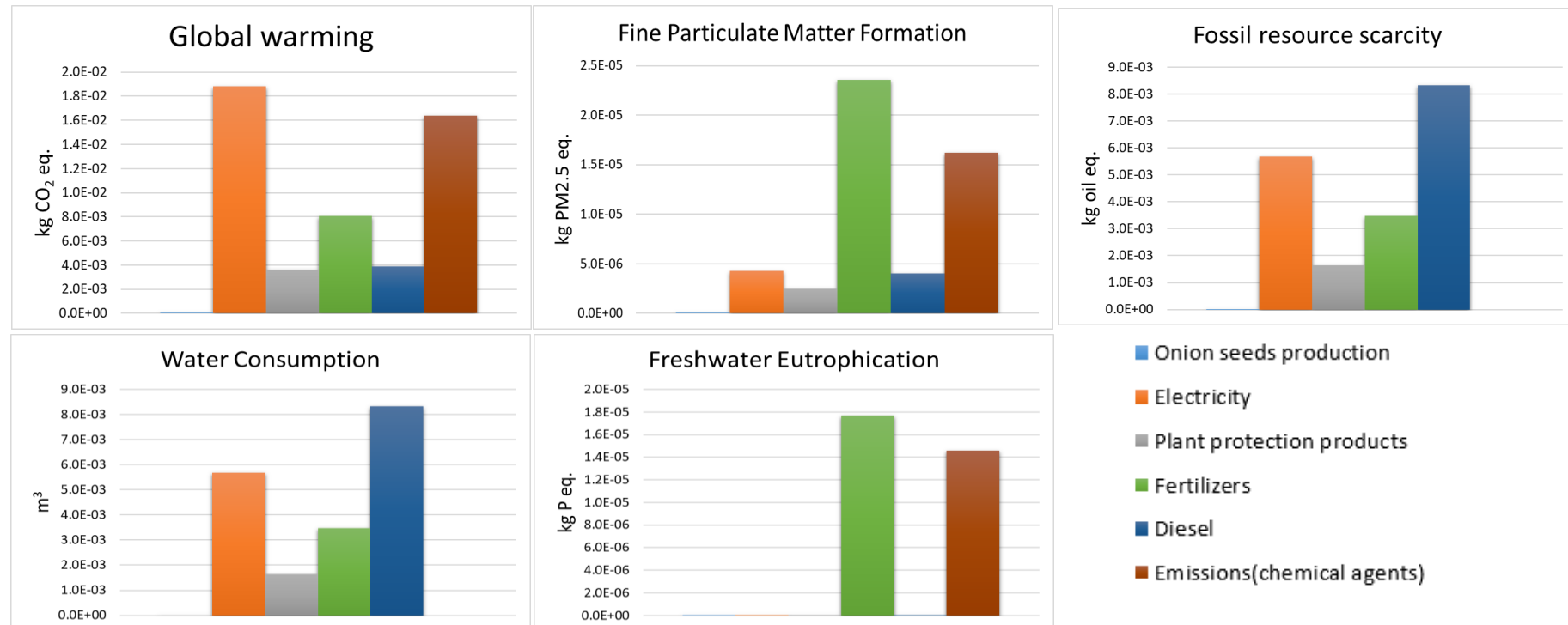


Figure 22: Contributing processes to the midpoint impacts per ha for the baseline scenario – Dutch UC (onions).

Impact category	Unit	Potato seeds production	Energy (Electricity)	Plant protection products	Fertilizers	Energy (Diesel)	Emissions (chemical agents)
Global warming	kg CO2 eq	13.55%	28.38%	13.30%	36.55%	8.22%	0.00%
Stratospheric ozone depletion	kg CFC11 eq	36.50%	0.57%	1.44%	61.08%	0.42%	0.00%
Ionizing radiation	kBq Co-60 eq	2.02%	67.59%	15.46%	11.02%	3.89%	0.00%
Ozone formation, Human health	kg NOx eq	1.43%	65.09%	23.17%	4.58%	5.73%	0.00%
Fine particulate matter formation	kg PM2.5 eq	22.24%	3.82%	10.41%	58.51%	5.02%	0.00%
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.41%	65.22%	23.09%	4.57%	5.71%	0.00%
Terrestrial acidification	kg SO2 eq	37.52%	2.79%	7.96%	47.85%	3.88%	0.00%
Freshwater eutrophication	kg P eq	90.43%	2.90%	3.40%	0.21%	3.06%	0.00%
Marine eutrophication	kg N eq	97.06%	1.19%	0.68%	0.40%	0.67%	0.00%
Terrestrial ecotoxicity	kg 1,4-DCB	14.32%	0.17%	0.19%	0.13%	0.12%	85.07%
Freshwater ecotoxicity	kg 1,4-DCB	38.58%	0.02%	0.56%	1.78%	0.14%	58.92%
Marine ecotoxicity	kg 1,4-DCB	3.82%	0.01%	0.10%	0.27%	0.05%	95.76%
Human carcinogenic toxicity	kg 1,4-DCB	3.82%	18.67%	22.05%	24.03%	31.44%	0.00%
Human non-carcinogenic toxicity	kg 1,4-DCB	94.10%	0.10%	1.18%	2.52%	2.10%	0.85%
Land use	m ² a crop eq	0.00%	37.99%	20.95%	1.33%	39.74%	0.00%
Mineral resource scarcity	kg Cu eq	0.09%	0.43%	1.88%	97.30%	0.30%	0.00%
Fossil resource scarcity	kg oil eq	4.56%	16.64%	13.75%	30.91%	34.13%	0.00%
Water consumption	m ³	22.46%	29.00%	29.54%	7.06%	11.94%	0.00%

Table 34: Percentage contribution of each flow in the various midpoint indicators – Dutch UC, baseline scenario (potatoes).

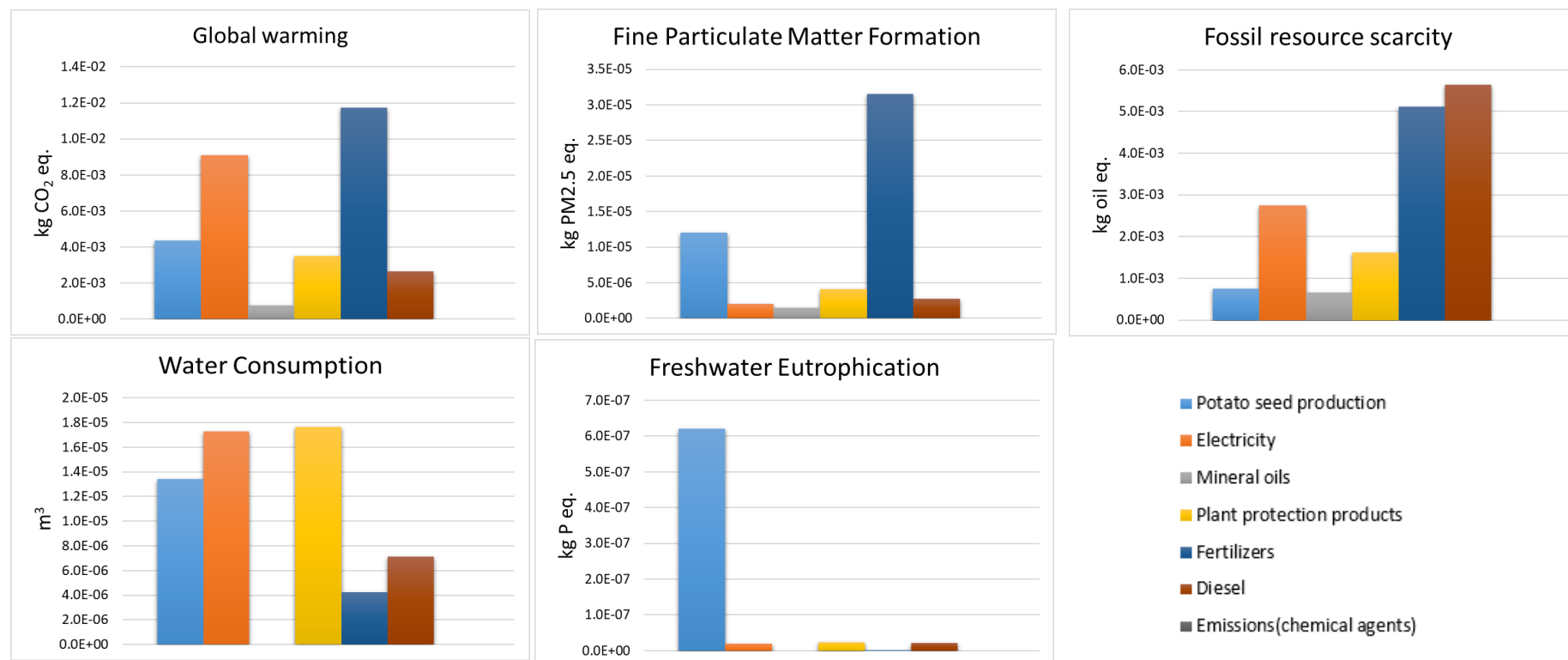


Figure 23: Contributing processes to the midpoint impacts per ha for the baseline scenario – Dutch UC (potatoes).

In the case of onion cultivation, the main contributors to the midpoint impact categories are the use of plant protection products (fungicides, insecticides, herbicides, etc), the use of electricity for the farming activities and the emissions from the plant protection products applied. Moreover, the contribution of fertilizer use in the various environmental impact categories is quite significant. Specifically, the global warming potential is affected equally by the use of electricity (37%) and the application of pesticides, fungicides, insecticides, etc (32% in total), whereas fertilizers contribute up to 16% in this midpoint impact category. The production of synthetic fertilizers is responsible for 47% of the total impact on total fine particulate matter formation, followed by the emissions from the plant protection products applied. Fossil resource scarcity, as expected, is attributed to the use of fossil fuels (diesel) and electricity for the farming activities, at a percentage of 44% and 30%, respectively.

In the case of potato cultivation, a greater but quite low (order 10^{-5} - 10^{-7}) contribution of the potato seeds embodied impact is observed to the total environmental impact, especially to the freshwater eutrophication. This can be attributed to the great amount of potato seeds that are required and the amount of fertilizers and plant protection products that are used for their production. Global warming is affected similarly by various inputs, including fertilization and energy consumption and followed by potato seed production and application of plant protection products. The use of diesel and the production of synthetic fertilizers are responsible for a significant percentage of fossil resource scarcity, followed by the use of electricity.

3.5.4 Interpretation of LCA results– Dutch UC (onions & potatoes cultivation)

The main environmental impact of the Dutch UC on each midpoint impact category is attributed to the application of plant protection products and the use of electricity for farming activities. The objectives of next year's studies will involve evaluating the potential of the selected CSA practices to reduce this impact in key categories, including global warming, fossil resource scarcity, and water or marine ecotoxicity, through outcomes such as energy credits, decrease of plant protection products or reduction of energy consumption.

3.5.5 Life Cycle Cost Analysis (LCC) – Dutch UC (onions & potatoes cultivation)

For the calculation of the life cycle costs of potato and onion cultivation (Dutch UC, baseline scenario), only OpEx were taken into account as any equipment, land, building or other CapEx are considered to have been depreciated and only maintenance costs are taken into account. In Figures 24 and 25 the expenditures are presented, along with the revenues including subsidies and sale of potatoes and onions. The total costs per crop per ha are calculated up to 6,700 € - 6,900 € per ha and the revenues vary at 9,600€ - 10,000€ per ha, leading to an average profit about 2,900 – 3,100 € per ha.

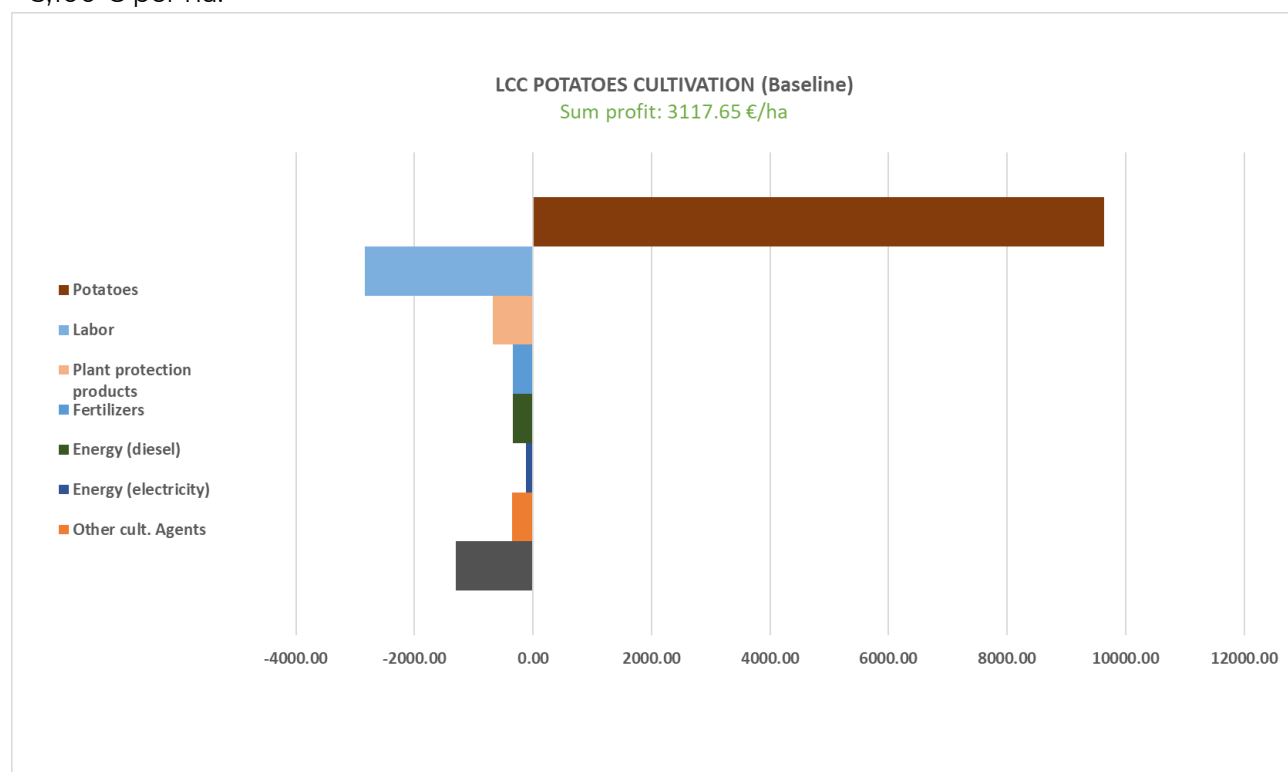


Figure 24: Life Cycle Cost Analysis of the Dutch UC (potatoes) per ha per year, baseline scenario (Positive values correspond to annual revenues, negative values correspond to annual expenses).

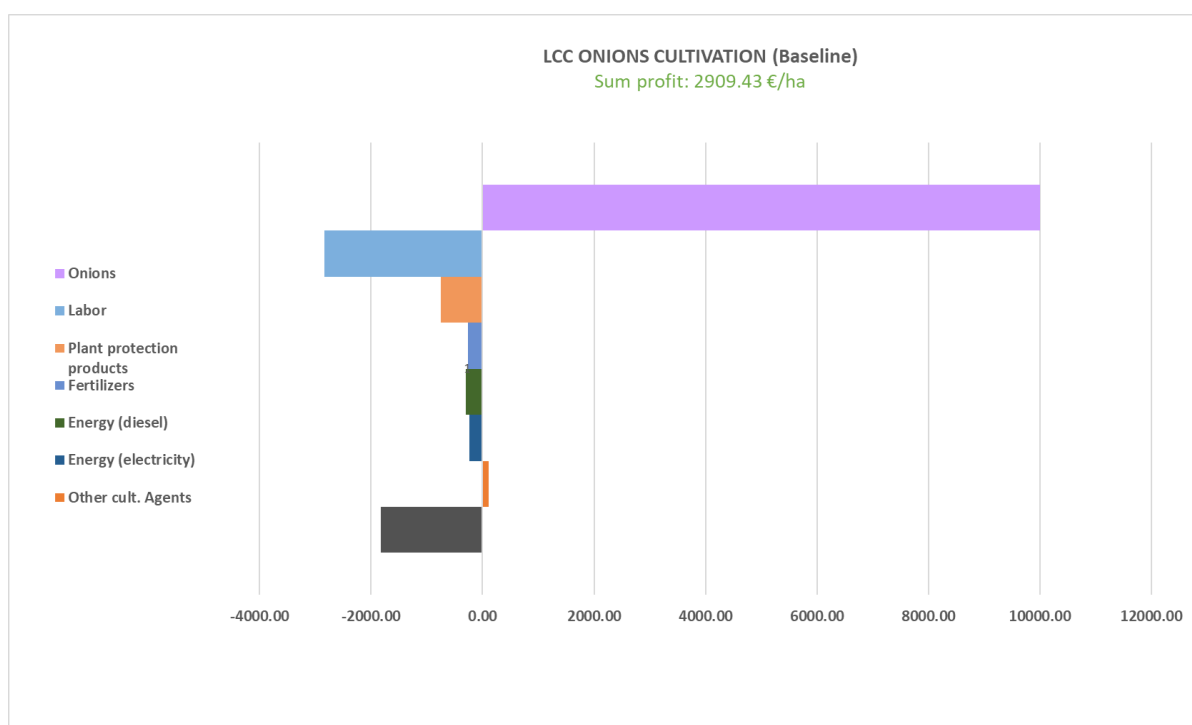


Figure 25: Life Cycle Cost Analysis of the Dutch UC (onions) per ha per year, baseline scenario (Positive values correspond to annual revenues, negative values correspond to annual expenses).

3.5.6 Social Life Cycle Impact Assessment (s-LCIA) and interpretation of results – Dutch UC (onions & potatoes cultivation)

The production flows and relevant inventory data of the Dutch Baseline scenario were taken from the resulting LCIA shown in previous section 3.5.2. Data inputs and calculated results for the social indicators of the Danish Baseline scenario are presented in Table 35. Values in bold were values taken directly from the distributed questionnaire, while values with normal fonts were taken directly from the data sources presented in Table 4. Regarding the “Worker hours” activity variable, the Unit labor cost was calculated based on an annual production of 50 tonnes of onions and 48.2 tonnes of potatoes per hectare and an average annual compensation of 30000 € per hectare. The hourly labor costs were calculated assuming 4.5 weeks/month. The activity variable was used in every indicator and the respective DALYs were calculated. Note that some indicators give combined results (e.g. the 3 wage indicators have combined output as “Fair Salary” - see Table 35 & Figure 26):

$$\text{Unit Labour Costs} = \frac{30000}{98200} = 0.3055 \text{ €}$$

and

$$\text{Worker hours} = \frac{0.3055 \text{ €}}{13.8888 \text{ €/h}} = 0.0220 \text{ h}$$

Indicator	Value	Risk level	Calculated DALYs
Children in employment, male	No Data	No Data	70638.96
Children in employment, female	No Data	No Data	12665.13
Children in employment, total	No Data	No Data	12637.17
Frequency of forced labor	0.6	Very Low	27898.67
Good produced by forced labor	No Data	No Data	122.43
Trafficking in persons	1	Very Low	2463.93
Living wage, per month	1120	Very High	-
Minimum wage, per month	0.49	Very Low	-
Sector average wage, per month	1.70 & 3.48	Very Low	-
Fair Salary	-	-	54655.21

Hours of work per employee, per week	40	Low	5998.49
Women in the sectoral labor force	0	Very High	2615.19
Men in the sectoral labor force	1	No Risk	10.63
Gender wage gap	44.28%	Very High	9750.90
Accident rate at workplace, non-fatal	0	Very Low	311.84
Accident rate at workplace, fatal	0	Very Low	79.03
DALYs due to indoor and outdoor air and water pollution	5.50	Low	767.75
Presence of sufficient safety measures	Yes	Very Low	8932.02
Workers affected by natural disasters	0.0017%	Very Low	396.18
Social security expenditures	15.69%	Low	58629.15
Evidence of violations of laws & employment regulations	0.1<y<1	Low	4807.05
Trade union density	15.4	Very High	59414.33
Right of Association	2	Low	-
Right of Collective bargaining	2	Low	-
Right to Strike	2	Low	-
Association and Bargaining rights	-	-	3054.34
Presence of anti-competitive behavior or violation of anti-trust & monopoly legislation	0.0461	Very Low	68047.98
Public sector corruption	79	Low	76978.10
Active involvement of enterprises in corruption & bribery	4%	Low	12167.43
Membership for social responsibility along supply chain	Some	Medium	5654.38
Global Peace Index (Risk of Conflicts)	1.49%	Low	7510.88
Contribution of the sector to economic development	2.07	Low Opportunity	708.51
Value added (total)	-	-	311.83
Public expenditure on education	8.65	Low	589.36
Adult illiteracy rate (15+ years), male	0	Very Low	60485.69
Adult illiteracy rate (15+ years), female	1	Very Low	73677.85
Adult illiteracy rate (15+ years), total	1	Very Low	70681.16
Youth illiteracy rate, male	0	Very Low	6124.89
Youth illiteracy rate, female	0	Very Low	6070.98
Youth illiteracy rate, total	0	Very Low	7129.53
Health expenditure, total	11.10%	Low	-
Health expenditure, public	68.80%	Low	-
Health expenditure, out-of-pocket	9.30%	Very Low	-
Health expenditure, external resources	0.00%	Very Low	-
Health expenditure	-	-	27210.79
Life expectancy at birth	81	No Risk	10287.86
Violations of mandatory health and safety standards	29E-7	High	-
Level of industrial water use (Total Withdrawal)	No Data	No Data	-
Level of industrial water use (Renewable resources)	No Data	No Data	-
Industrial water depletion	-	-	2868.80
Extraction of materials per population (Fossil fuels)	0.89	Very Low	11.63
Extraction of materials per population (Ores)	0.00	Very Low	-
Extraction of materials per population (Minerals)	5.25	Medium	-
Minerals' consumption	-	-	1478.90
Extraction of materials per population (Biomass)	2.68	Low	-
Extraction of materials per area (Biomass)	1137.81	Very High	-
Biomass consumption	-	-	69427.83
Certified Environmental Management Systems	No	Very High	16428.95
Presence of indigenous population	No	No Risk	-
Indigenous Rights Protection Index	4	Low	-
Indigenous rights	-	-	1649.33
Pollution level of the country	21.8	Low	9985.13
Drinking water coverage (urban, rural, total)	100% & 100%	No Risk	86363.75
Sanitation coverage (urban, rural, total)	97.50% & 97.47%	Very Low	40046.48
Unemployment rate	3.5	Low	9760.78
International migrant workers in the sector	0	No Risk	28225.23
International migrant stock	11.7	High	1133.06
Net migration rate	4.1	Low	201.67
Immigration rate	0.0118	Medium	-
Emigration rate	0.0057	Medium	-
Asylum seekers rate	1.91E-04	Very Low	-
Migration flows	-	-	4860.99
GHG Footprints	No Data	No Data	24235.50
Embodied agricultural area footprints	No Data	No Data	377.73

Embodied biodiversity footprints	No Data	No Data	34961.52
Embodied forest area footprints	No Data	No Data	14.17
Embodied water footprints	No Data	No Data	1675.54

Table 35: S-LCA Data for the Dutch Baseline scenario of the BEATLES project: Indicator values, associated risk levels and calculated DALYs for 1 year of production (Values in **bold** are data taken from the distributed questionnaire)

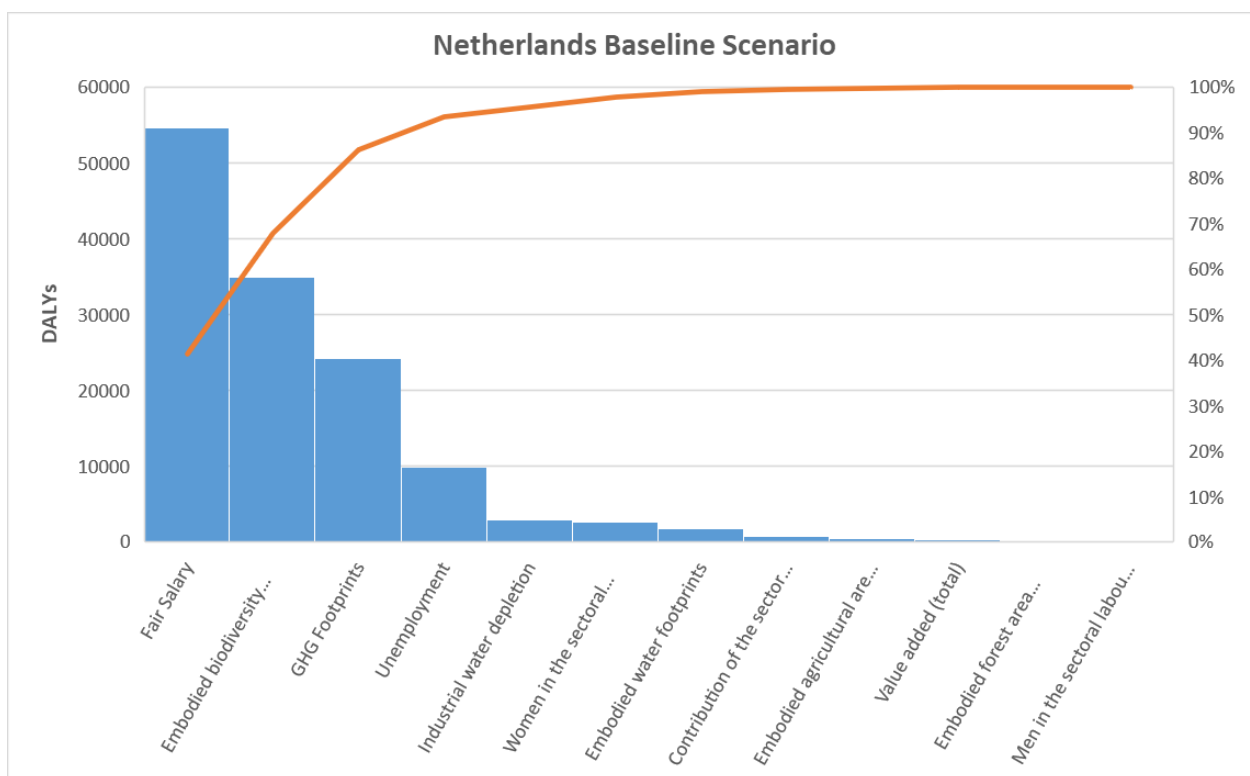
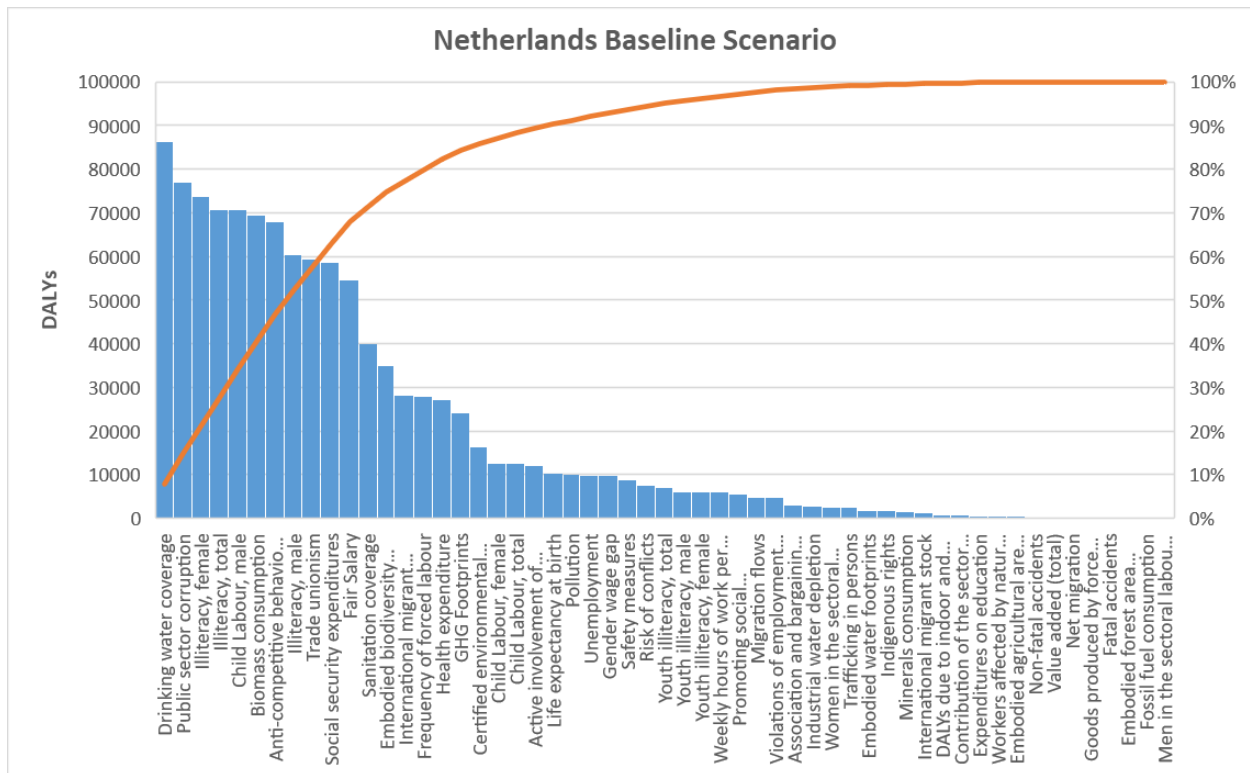


Figure 26: (**Top**) Pareto chart with S-LCA results from the Dutch Baseline scenario of the BEATLES project for 1 year of production showing all evaluated SOCA 2 indicators and (**Bottom**) same Pareto chart

simplified to include only the EU CAP-relevant indicators (The orange line is the Pareto line of aggregate percentages of the factors on the X axis)

The S-LCA analysis of the Dutch Baseline scenario resulted in total 1103192.57 DALYs. The 7 most impactful factors were the Drinking water coverage (86363.75 DALYs), followed by Public sector corruption (76978.10 DALYs), Female illiteracy rate (73677.85 DALYs), Total illiteracy rate (70681.16 DALYs), Male child labor (70638.96 DALYs), Biomass consumption (69427.83 DALYs) and Anti-competitive behavior (68047.98 DALYs). These factors account for ~45% of the total resulting DALYs. On the other hand, the least impactful factors were the Men sectoral labor force (10.63 DALYs), followed by Fossil fuel consumption (11.63 DALYs) and Embodied forest area footprints (14.17 DALYs). These contributed <0.005% to the total resulting DALYs.

Focusing on the CAP-relevant indicators that are more in accordance with the BEATLES project (Figure 26 Bottom), the 4 most important factors were the Fair Salary (54655.21 DALYs), followed by Embodied Biodiversity Footprints (34961.52 DALYs), GHG Footprints (24235.50 DALYs) and Unemployment rate (9760.78 DALYs). Judging by the relevant inputs and risk assessments in Table 34, these high-risk results for the aforementioned indicators were not expected, as the associated risks ranged from No Data-Low (Embodied biodiversity Footprints, GHG Footprints, Unemployment rate) to very low (Fair Salary). However, since the analysis is conducted on a Life Cycle basis on global scale, there are several upstream flows that contribute to overall risks, and indeed it was found that most of the risks were associated with the flow related to the production and use of the fertilizers on global scale, followed by production and use of low voltage electricity and production of potato seeds for sowing. It is anticipated that a change in production flowcharts and/or the applied activity variables due to an application of a CSA practice might cause a desired reduction to some of these high-risk impacts.

3.6 Theory of Change (ToC)

The overall status of the ToC in terms of the established short/mid-term outcomes as outlined in the ToC strategy is presented for all completed activities in Figure 27. Current completion rate is around 22%, nevertheless, it is expected that ongoing/upcoming activities and events will significantly contribute to the established targets (e.g. EU multi-actor workshop, Farmer Field study etc.). More details are presented in below sections for each activity (3.6.1-3.6.4).

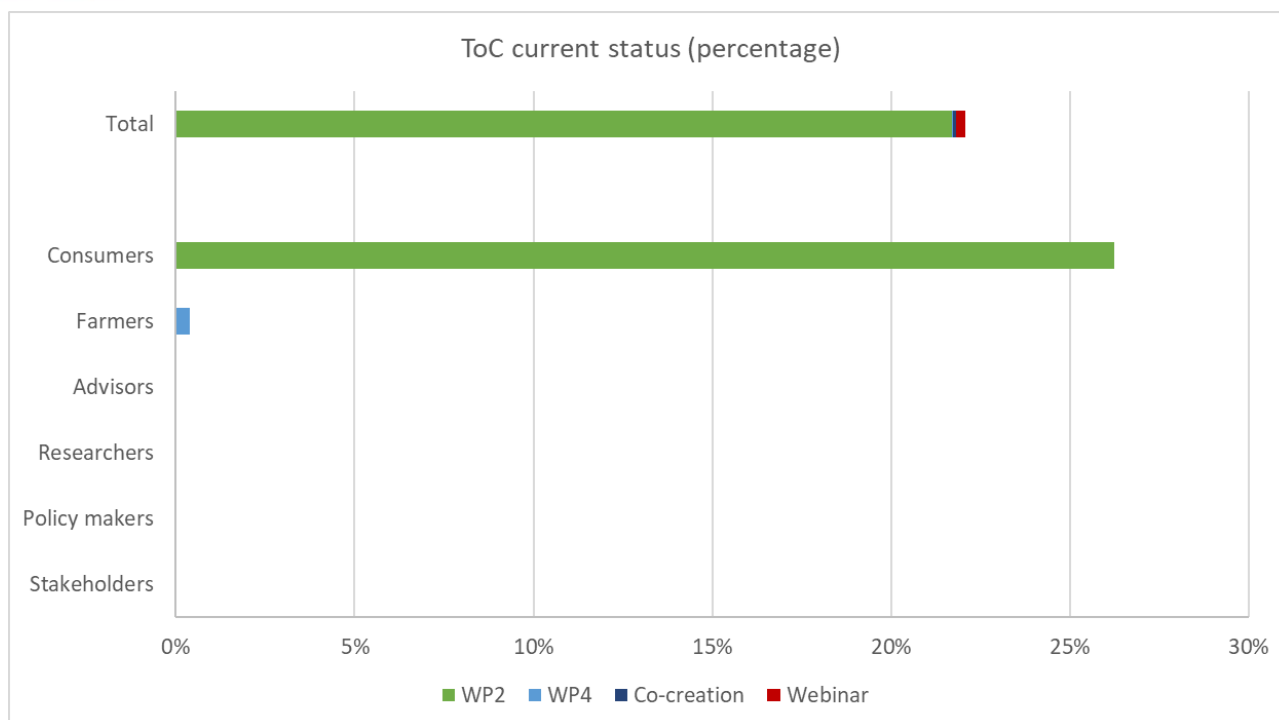


Figure 27: Current status of completion of short/mid-term outcomes of the ToC strategy

3.6.1 Consumer survey (WP2)

The consumer survey of WP2 included two ToC-relevant questions for consumers, involving the increase of awareness for climate friendly food production and willingness to change the consumption preferences towards products that are produced in a more sustainable way. The relevant results from the consumer survey of WP2 are presented below (Figure 28). Overall, the survey got a total of 3606 responses, out of which around 42% were positive, 25% negative and 33% neutral, meaning a lot of consumers increased their awareness and are willing to change to food products that are produced in a more sustainable way.

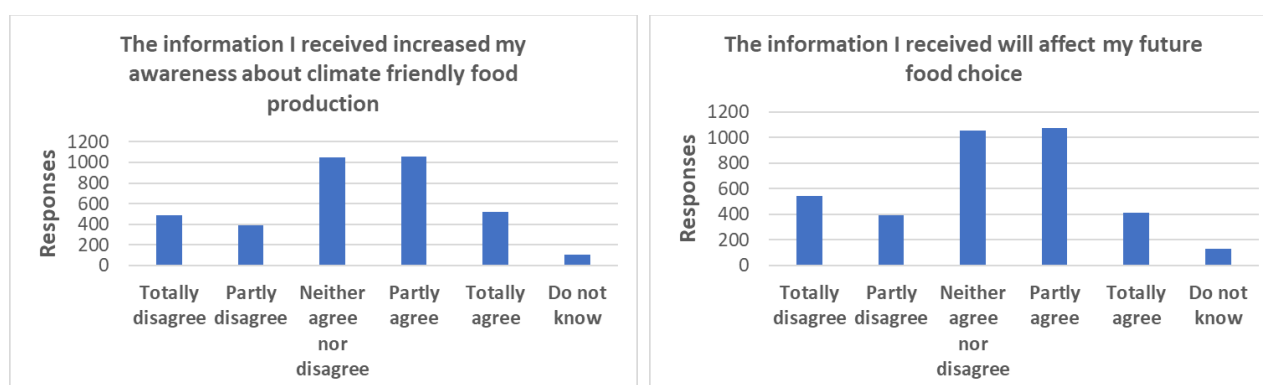


Figure 28: ToC results from the consumer survey

3.6.2 Farmer questionnaires (WP4)

The farmer questionnaires of WP4 about the applied business models included three ToC-relevant questions for farmers, involving questioning about their applied business model, the willingness to change it and the recommendation of the BEATLES project. The relevant results from the farmer questionnaires of WP4 are presented below (Figure 29). Overall, the questionnaires got a total of 7 responses, out of which around 43% were positive, 43% negative and 14% neutral, meaning that although some farmers did gain valuable knowledge about their applied business model and started thinking about it, a lot of them still did not seem to benefit from the change in their

business model, maybe either because they already implementing what was suggested, or they find the benefits from such change to be minimal, or they were expecting something else. At this point though it should be noted that overall, the total responses are currently are too low to drive any safe outcomes.



Figure 29: ToC results from the farmer questionnaires

3.6.3 Co-creation workshop

The co-creation workshop questionnaire included in total 13 ToC-relevant questions for farmers, organizations, advisors, product suppliers, policy makers, researchers, NGOs and consumers. Some of the questions were dependent on the category of the responder and some on their responses to previous questions. The main topic of the workshop was the fairness of the food value chains and it investigated whether it can be improved through changes in the applied business models and the relevant policies. Overall, the questionnaires got a total of 15 responses. The first questions identified how the person who was taking the questionnaire became aware of the event and in which category they belong to (Figure 30). Although the responses were very limited, it seems that most persons either knew already someone linked with the project, or followed it up from a previous event of the project. Regarding the categories, the responses were quite broad, something that reflects on the purpose of this co-creation event.

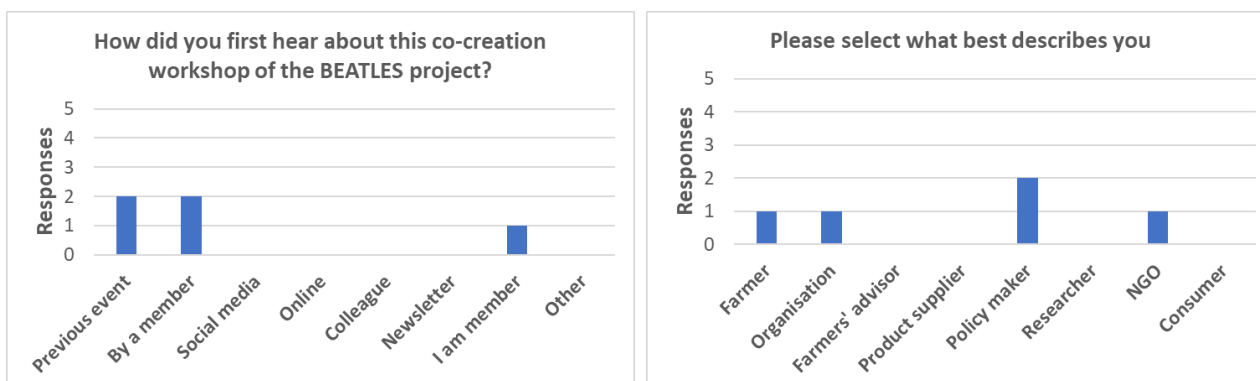


Figure 30: Results from the identification questions of the co-creation workshop

The next questions examined the perception of fairness that the respondent had and their willingness to change towards a fairer one, as well as the factors that hinder or drive such change. From the results, it seems that the respondents found that their value chain of interest is overall fair, but there is plenty room for improvement and indeed some respondents seem to consider the proposed changes to a fairer value chain. The main factors that hinder adoption of the change seem to be the costs for implementation and various legal aspects. On the other hand, some farmers that consider applying the required changes expect to increase the competitiveness of their products on the markets and improve the sustainability of their products. Regarding the workshop, the respondents were overall positive and stated that it improved their knowledge about fairness and helped them prioritize what is needed for fairer food value chains (Figure 31).

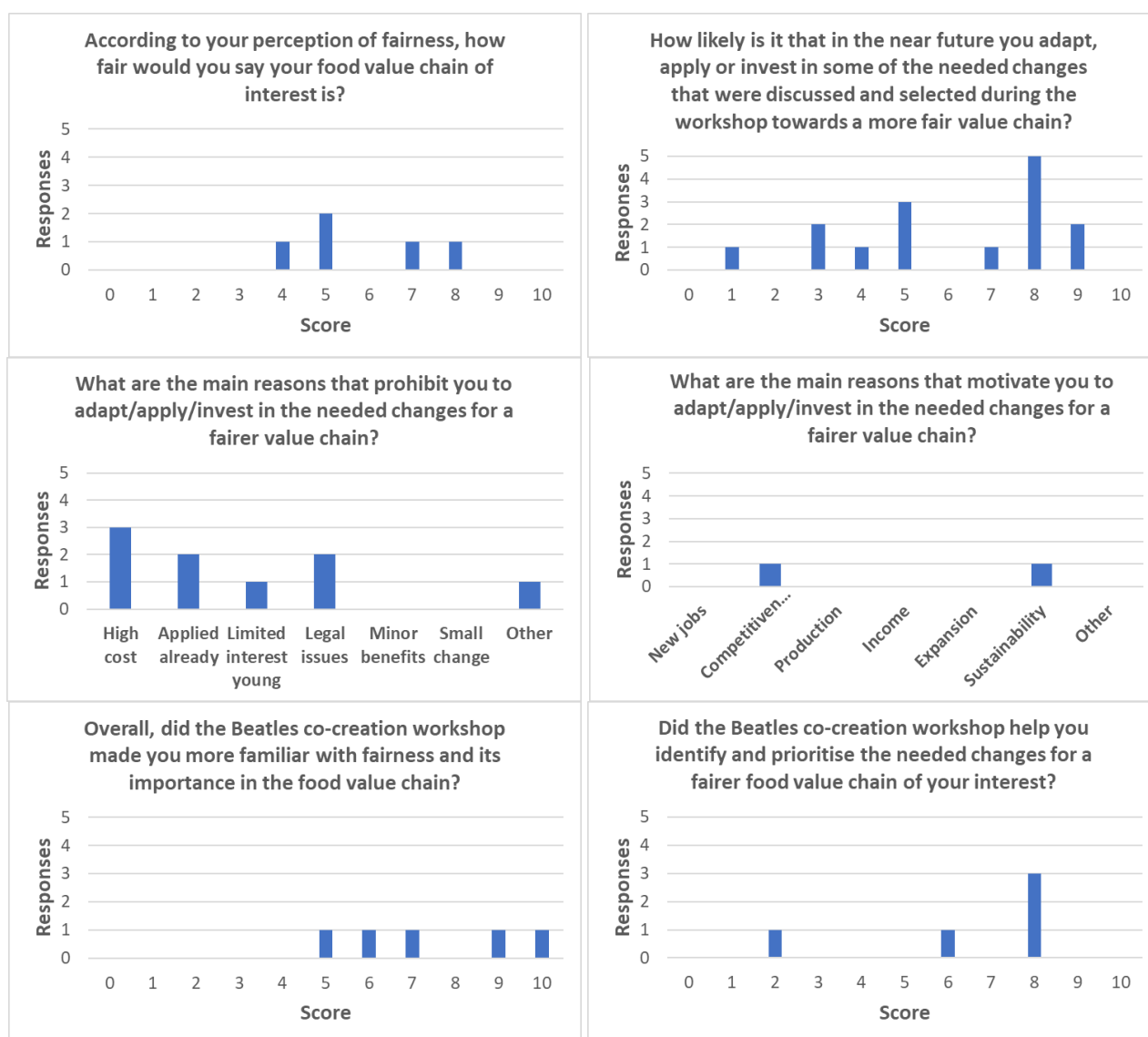


Figure 31: ToC results from the fairness-related questions of the co-creation workshop

Regarding the applied business models and relevant policies and their relation with fairness in value chains, the respondents gave generally positive answers, meaning that they improved their knowledge about the needed changes and the various policy aspects they might face (Figure 32).



Figure 32: ToC results from the business model & relevant policies questions of the co-creation workshop

Finally, the respondents were generally positive about the event, with the majority answering that was satisfied and that would recommend it to a colleague. On the other hand, it's interesting to point out that some reason for dissatisfaction was that some found that the workshop contained little information and solutions regarding their local value chain (Figure 33). At this point though it should be noted that overall, the total responses are currently too low to drive any safe outcomes.

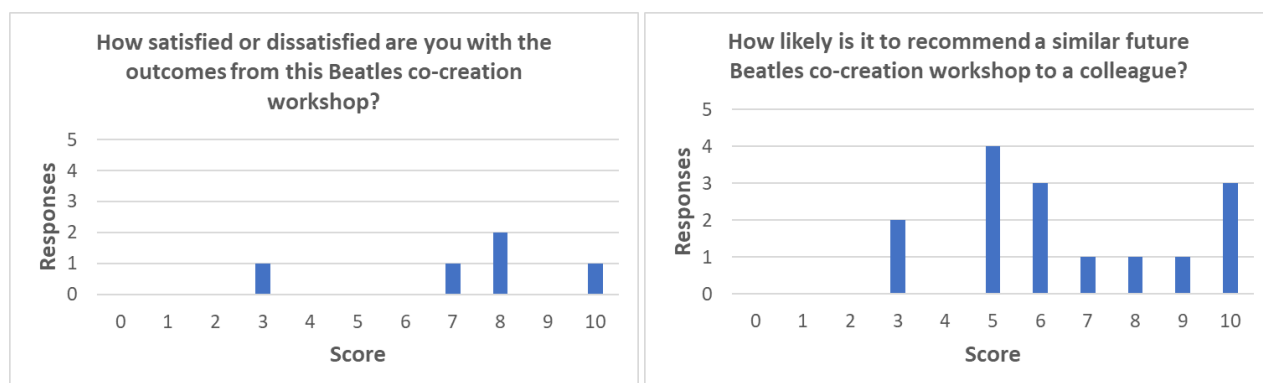


Figure 33: ToC results from the general evaluation questions of the co-creation workshop

3.6.4 Webinar

The BEATLES webinar included a ToC questionnaire with four ToC-relevant questions, mainly for consumers and farmers, involving the increase of awareness for climate smart agriculture and willingness to change the consumption preferences towards products that are produced in a more sustainable way. The relevant results from the consumer survey of WP2 are presented below (Figure 34). Overall, the questionnaire got a total of 33 responses. Mostly the responses were positive towards both increase of awareness and change of behavior (around 60% and 70% respectively), while most respondents stated that they were satisfied from the webinar (around 70%) and almost everyone would recommend a colleague to follow future updates of the project.

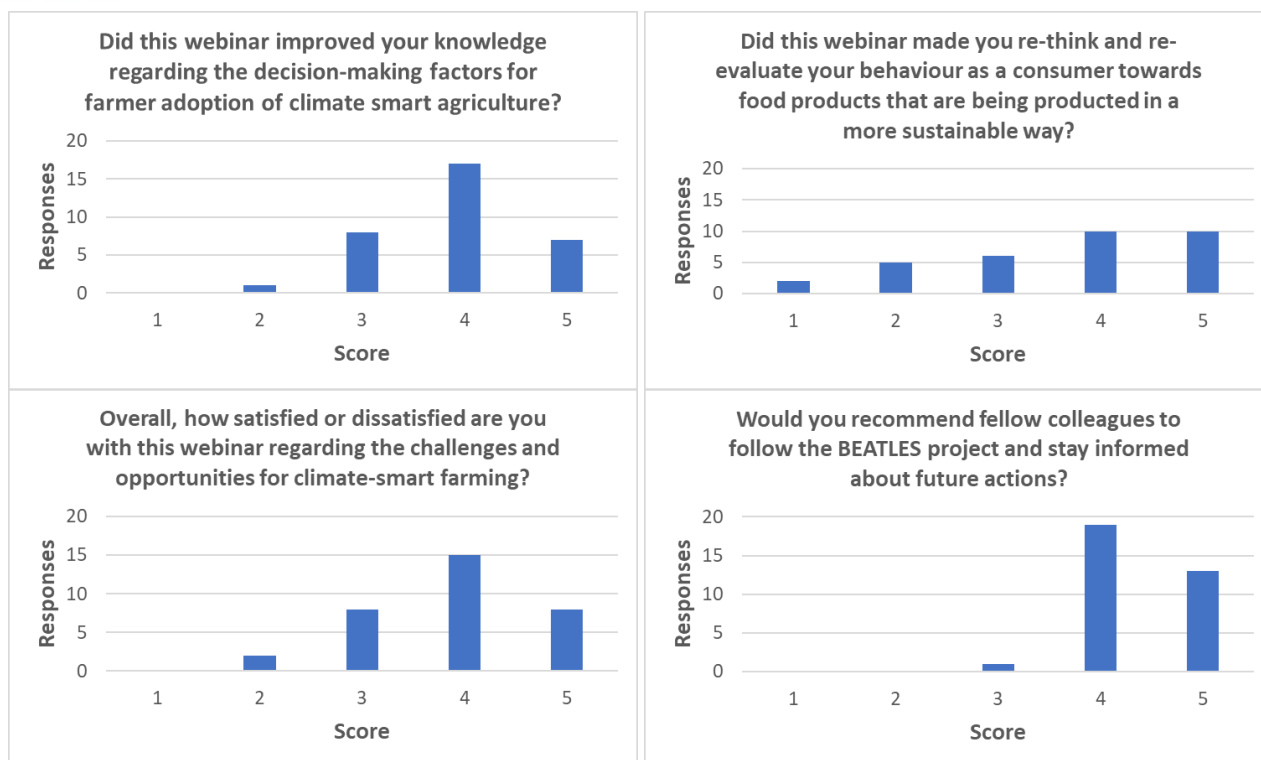


Figure 34: ToC results from the webinar

Finally, a lot of respondents provided their feedback regarding both the webinar and the project (Figure 35). Some interesting responses were the need to look at a whole systems perspective, to consider more the supply chains, to include soil health parameters, to investigate feasibility of the policy recommendations and to introduce the project to the private sector.

“Invite the Private sector to the webinar: farmers, retail, and packaging - present results to them and ask their feedback.”

“Very tight schedule”

“Very interesting project, will follow in the future”

“Short term and long term capacity building for researchers who are close to farmers share experience each other in person session”

“I am really interested in hearing more about policy recommendations and potential business models recommendations that will come from the project.”

“in the Miro board maybe put instructions somewhere just in case you fail to understand the speaker or you just forget them :)”

“think more in supply chains / value chains than from a farmer perspective”

“living lab in context of soil health”

“I think we need to look at a whole systems perspective rather than perpetuating the existing silos, i.e. wheat, pigs, onions, dairy etc. We need to understand relationships and feedbacks within integrated agricultural systems at all scales from field to farm to local, regional, national and global supply chains, and relate these to current and future challenges, including the climate, biodiversity and energy crises.”

“Regarding policy instruments, it's key to assess not only acceptability and effectiveness, but also consider practical and political feasibility to implement. happy to exchange further with ENFASYS partners”

Figure 35: Feedback responses for the webinar

4. Conclusions

The analysis of various agricultural and livestock systems reveals significant environmental impacts attributable to specific practices and inputs. Across all the studied UCs, key contributors to environmental burdens have been identified, and targeted strategies for mitigation have been outlined for future activities.

More specifically, the analysis of the environmental impact of the baseline wheat farm reveals that synthetic fertilizers and diesel consumption are the primary contributors to its environmental burden. The most affected impact categories are global warming and fossil resource scarcity. To address the environmental burden of the wheat farm, diesel and synthetic fertilizer use must be reduced. In the baseline scenario of dairy farming, the primary environmental impacts are from the emissions of the livestock management, the fertilizer use, and the maize cultivation, which significantly contribute to global warming, fine particulate matter formation, and terrestrial acidification. Efforts to mitigate these impacts should focus on reducing emissions from manure management and improving feed production efficiency. Additionally, energy credits from renewable sources can be explored to offset diesel use in farm equipment. In the case of the Spanish baseline scenario (apples farm), the diesel use for energy production and the application of synthetic fertilizers are the main contributors to environmental impacts, including global warming, fossil resource scarcity, and freshwater ecotoxicity. CSA practices that reduce diesel use, improve energy efficiency, and decrease synthetic fertilizer application should be applied in order to mitigate these impacts. In the baseline scenario of pig farming, the major contributors to environmental impacts, especially global warming and fossil resource scarcity, are the housing system and the emissions from pig fattening. The production of pig feed also significantly affects water consumption and eutrophication. The CSA practices that will be applied should focus on reducing energy consumption in housing systems and minimizing emissions through improved manure management practices. In the baseline scenario of onion and/or potato cultivation, the main burden is attributed to the use of plant protection products and electricity/diesel. Mitigation efforts should focus on reducing fertilizer application, and improving energy efficiency to address global warming and fossil resource scarcity.

Across all UCs, the use of synthetic fertilizers and diesel are common contributors to environmental burdens. Targeted mitigation strategies, including the adoption of CSA practices, renewable energy sources, and improved management techniques, will be evaluated in the next year to reduce the environmental impacts identified in the current analysis. This comprehensive approach aims to enhance sustainability and efficiency across various agricultural and livestock systems.

The Social Life Cycle Assessment (S-LCA) analysis of the baseline scenarios for the Lithuanian, German, Spanish, Danish, and Dutch agricultural systems revealed significant insights into the social impacts of these operations. Overall, these analyses highlight that while direct risk assessments may indicate low or very low risks, the comprehensive life cycle approach uncovers significant upstream social impacts. The high impact factors across all scenarios commonly involved issues related with fair salaries, embodied biodiversity footprints and GHG footprints, pointing to areas that require targeted interventions to mitigate adverse social impacts.

The LCA, LCC and s-LCA assessments of the conventional scenarios presented in the current deliverable will be used as a baseline for the comparison with scenarios that include the CSA practices selected this year. The aim of this study, which will take place in next year's activities, is to evaluate the environmental, economic and social impacts of the selected CSA practices.

Finally, the findings across the ToC surveys indicate a strong consumer interest in sustainable food production and a mixed but cautiously optimistic response from farmers regarding business model changes and the BEATLES project recommendations. The co-creation workshop and webinar were particularly effective in increasing awareness and understanding of fairness and

sustainability in value chains, though more targeted and localized information may be needed to address specific concerns and increase engagement. The limited response rates in some areas highlight the need for broader participation to ensure more robust conclusions.

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Appendix

Questionnaire for data collection (S-LCA)							
Category	Questions	Unit	Current situation		CSA		
			WOMEN	MEN	WOMEN	MEN	
Workers	Number of employees	No.					
	Average age of the workforce	Y					
	Number of new employees hired during the last year	No.					
	Yearly average salary of an employee?	€					
	Number of weekly working hours per employee	h					
	Number of overtime working hours computed in the last year or month (per level of employment)	h/month or h/y					
	Number of labor accidents in the last year	No.					
	Presence of sufficient safety measures	Yes/No [Name]					
	Are employees trained on how to work safely ?	Yes/No					
	Does the organisation provide protective gear or are employees responsible for their own gear?	Yes/No					
Value chain actors	Does your organisation/facility have obtained any certification/label? Which one?	Yes/No [Name]					
	Is there any policy regarding the actions taken to reduce the chances of pollutants from the facility impacting on local communities'	Yes/No [Name]					
	From which countries does your sector buy equipment/materials?	[Name]					
	Is your organisation member of any initiative that promotes social responsibility among the supply chain?	Yes/No [Name]					

	Is there any internal Intellectual Property Rights policy to protect the products and R&D conducted by your organisation?	Yes/No [Name]		
Local community	Does your organisation have a certified environmental management system?	Yes/No [Name]		
	How much water does your organisation needs at annual basis?	Mm3		
	Does your organisation measures CO, CO2, NOx, SO2, CH4, NH4 and volatiles emissions from production and if so how much are they?	Yes/No [Value]		
	Does your organisation purchases/uses any antimicrobials? If so which ones and how much?	Yes/No [Quantities]		
	Does your organisation purchases/uses any fertilizers? If so which ones and how much?	Yes/No [Quantities]		
	Does your organisation purchases/uses any pesticides? If so which ones and how much?	Yes/No [Quantities]		
	How many of your employees are originally from the region where your plant is located?	No. or %		
	Do employees from another city/country face (or faced) any issues regarding their human rights?	Yes/No [Name]		
	Is your organisation actively involved in community educational activities?	Yes/No [Name]		
	Does your organisation allows visits from local community's groups (e.g. schools) to your facilities?	Yes/No		
	What amount of the organisation resources are spent in educational activities?	% or €		
Society	What percentage of the organisation resources are spent in research and development?	% or €		
	What level of involvement does the organisation has in technology transfer projects?	[Describe]		
	What percentage of the organisation resources are spent in sustainability & social activities?	% or €		
	What potential issues do you identify consumers will have with the product	[Describe]		

	regarding their health and safety? How do you mitigate them?			
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Table A.1: S-LCA Data collection questionnaire