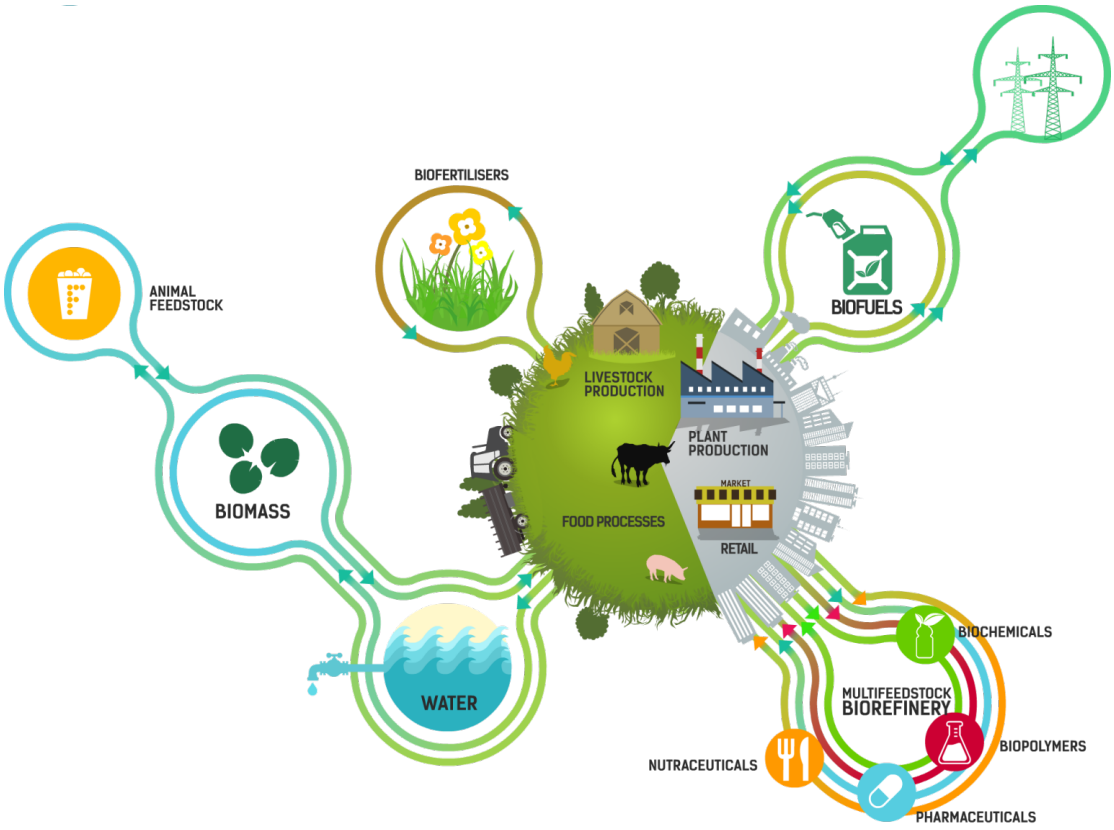
D6.1 Integrated Sustainability Assessment Framework

Including definition of the details, requirements and guidelines for LCA, LCC and S-LCA Analysis



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1 General information

Name:	AgroCycle Protocol Rules (APR) for Life Cycle Sustainability Assessment applied to agri-food waste and bi-product valorization (processes and products)
Programme operator:	AgroCycle
Publication date:	01/12/2016
This APR was prepared by:	UCD School of Biosystems and Food Engineering, University College Dublin.
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Contributors during open consultation	Mr. Thomas L. Oldfield Professor. Nicholas M. Holden Dr. Fionnuala Murphy
The APR is valid within the following geographical region:	Global

This document provides AgroCycle Protocol Rules (APR) for an assessment framework for the sustainability performance of agri-food waste and bi-product valorization (both processes and products are covered by this protocol).
This APR is suitable for application of life cycle assessment (LCA) methods to evaluate both the technology (e.g. anaerobic digestion, fermentation) and valorized product (e.g. energy, fertilizer) from agri-food waste and bi-products. Version 1.0 is to guide deployment of LCA methods for assessment of case studies from AgroCycle Work packages 2 to 5.
The LCA methods encompass impacts in the environmental (eLCA), social (sLCA) and economic (LCC) domains. These will be integrated into a Life Cycle Sustainability Assessment (LCSA) by the end of the project.
This APR document is publically available on http://www.agrocycle.eu. The APR document is a living document. If relevant changes in the LCA methodology or in the technology for the product category occur, the document will be revised and any changes will be published on the AgroCycle website (with an associated increment of version number, preparation date and publication date).
Any comments to this APR document may be given on the APR forum on the AgroCycle website (http://www.agrocycle.eu) or directly to the APR moderator (Chen.wenhao@ucdconnect.ie) during the period of validity.

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2 Definition of the product group

2.1 Specification of valorization company

The following mandatory information shall be described for an AgroCycle-LCA:

- Valorization company/organisation
- Valorization site and country
- Contact information of technical manager

Examples of voluntary information:

- ISO 14001 and/or EMAS certificate at the manufacturing site
- Any social responsibility guidelines followed (ISO 26000, GRI, UN Global Compact, UN Guiding Principles on Business and Human Rights, OECD Guidelines for Multinational Enterprises)
- Specific aspects regarding the production of raw materials and / or the technology itself
- Environmental policy of the company or policies associated with the technology / product
- Company/organisation logotype

2.2 Specification of the product

The trade name shall be declared, if relevant. Relevant Type I (third party programme) and Type II (self-declaration) environmental labels and social responsibility labels awarded to the product may be stated. Any claims made about the product must be independently verifiable. The properties of the value-added product from the valorization process may be specified in the AGROCYCLE-LCA.

In all cases the valorization method / technology must be declared. Examples of suitable pathways and products are:
Energy recovery: Include fuel, electricity, and gas. Each recovered energy should list its properties (e.g. fuel viscosity, calorific value, flash point, mix of energy resource etc.) and compare with standard form (e.g. ISO standards).
Nutrient recovery: Includes macro-nutrients (Nitrogen (N), Phosphorus (P), and Potassium (K)) and micro-nutrients. Nutrient availability should be included where possible (e.g. observed or default N, P, K values in agricultural waste for fertilizer production). The product type should be declared (e.g. digestate; compost; biochar).
Protein recovery: The properties of recovered protein need to be reported (e.g. quality of protein, key constituents and structures, the purpose and function (food or feed supplement), any co-products).
Material recovery: Material specification and replaced product (in a specified target market) need to be detailed, any co-products should be declared.
Water treatment: Water purification is not considered as valorization *per se*, so the APR is not suitable for this process. However, if any valuable products (e.g. protein) were created from a waste water treatment pathway then the APR can be applied.

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Details of any packaging (if applicable) shall be specified in the AGROCYCLE-LCA.
Valorization technologies, including some being developed by the AgroCycle project, may be in the research and development stage. They may take significant time to become commercially available. In order to carry out meaningful sustainability assessment of different valorization processes and products, suitable data should be defined according to the technology readiness levels (TRLs). TRLs (Figure. 1) are a method of characterizing technological maturity from the most basic research (TRL 1) through to full-scale real-world operation (TRL 9).
The data requirement for LCA modelling and sustainability assessment were defined as:
TRL 3/4 – Streamlined LCA, background data, some laboratory-based empirical observations.
TRL 5/6/7 – LCA using pilot plant specification and empirical observation, best available data.
TRL 8/9 – LCA using empirical observation from deployment specific to the technology, geography and time.

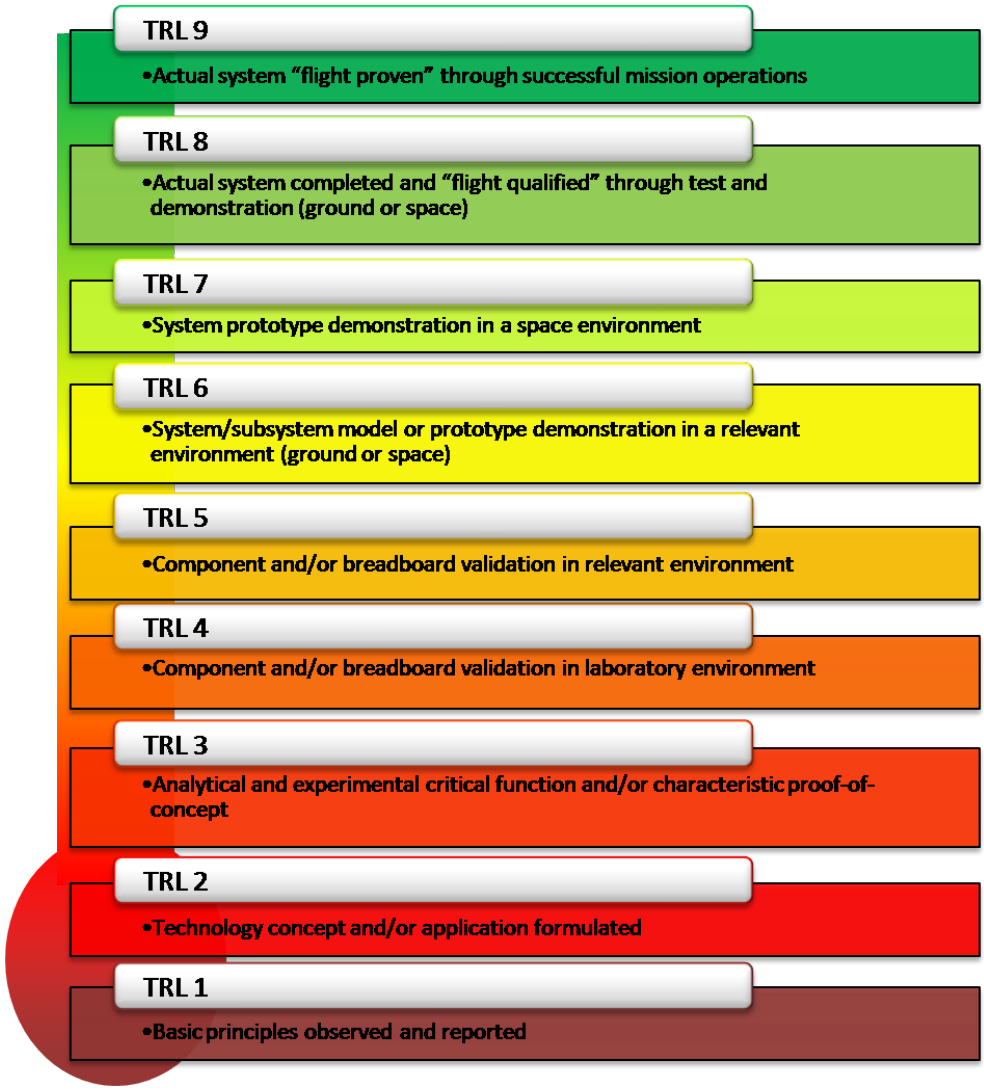

Figure 1 Diagram for Technology Readiness Levels (TRLs)

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3. Declared Unit

The declared unit (functional unit) shall be specific to the valorized product. The defined functional unit shall be related to the value-added product rather than the disposal of waste. Examples of possible functional units are:

- Energy: 1 MJ
- Nutrient: 1 kg (available N, P or K)
- Protein: 1 kg (of specified quality)
- Materials: 1 kg (of specified quality)

The environmental, economic (e.g. cost and benefit) and social (e.g. labour hours, number of jobs) impact shall be expressed per declared unit. The reference flow, in terms of throughput and years, shall be defined at the gate of the valorization process.

4. Content Declaration

The gross weight and energy (depending on the main function of product) of product / technology output shall be declared in an AGROCYCLE-LCA as a minimum of 95 % of one unit of product.

5. Units and quantities

The International System of Units (SI units) shall be used. Reasonable multiples may be adopted for a better communication (e.g. land use could be expressed in hectares (ha) rather than square metres)
Maximum of three significant digits shall be used for calculations and two significant digits when reporting LCA results.

6. General system boundaries

The AGROCYCLE-LCA calculations will be separated into three different life cycle stages, see Figure 1:

- Upstream processes (from cradle-to- valorization processor gate);
- Core processes (from valorization processor entry gate-to- exit gate)
- Downstream processes (from valorization processor exit gate-to-grave/cradle)

The resultant study will be a cradle-to-grave/cradle, as per the bioeconomy/circular-economy approach.

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In an AGROCYCLE-LCA, the environmental performance associated with each of the three life-cycle stages shall be reported separately. The system boundary should be defined according to TRLs:

For TRL 3/4, system boundary includes upstream processes with background data from database and/or literature sources.

For TRL 5/6/7, system boundary includes upstream processes with background data from database and/or literature sources, core process data with adequate technique details from observation and downstream processes with a defined end use case based on literature (unless empirical data are available).

For TRL 8/9, system boundary includes upstream processes with background data from database and/or literature sources (unless empirical observations are available), core process data with adequate technique details from observation and downstream processes with a defined end use case and observations.

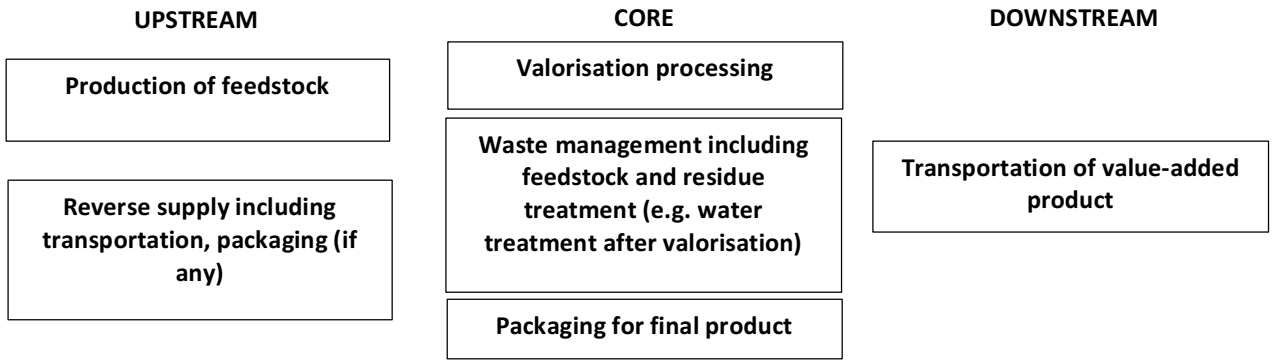

Figure 2. System diagram illustrating the main processes and the division into Upstream, Core and Downstream processes.

6.1 Upstream processes

The upstream processes comprise cradle-to-gate information. The upstream processes include the following:

- Extraction of resources (mineral exploration, energy generation, etc.)
- Production of waste/resource
- Reverse supply facility (for waste collection agricultural waste and transport to valorization facility) manufacture including transport of resources to refinement, packaging (if any)
- Refinement (e.g. pre-process) of resources not associated with the technology of interest (can be part of core process if refinement is essential to the valorization)
- Processes required to make raw materials suitable as feedstocks (can be part of core process if refinement is essential to the valorization)
- The production processes of energy used in the extraction, refinement and manufacturing
- Production of auxiliary products used such as detergents for cleaning etc
- The manufacturing of the primary and secondary packaging is also included in the core process

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6.2 Core processes

The core processes represent the production of the value-added product and will include gate to gate environmental information on the valorization stage. The core processes that may be considered:

- External transportation to the core processes
- Manufacturing of the value-added product
- Storage
- Treatment of waste generated from the core processes
- Impacts due to the electricity production according the proper energy mix hypotheses (see Section 7.4)
- Manufacture of valorization process equipment (optional for TRL 3-4; mandatory for TRL 5-9)

6.3 Downstream processes

The downstream processes include:

- Transportation from final manufacturing to an average retailer/distribution (weighted average)
- Use case (optional for TRL 5/6/7; mandatory for TRL 8/9)

7. Core Module

7.1 System boundaries

7.1.1 Technical system

The processes listed in Section 6.2 for the production of the final value-added product, including packaging, shall be included. Other manufacturing processes may also be included. The production of the raw materials used for production of specific technologies must be included.

The gross weight and energy (depending on the main function of product) of product / technology output including packaging shall be included.
The technical system shall not include:

- buildings and other capital goods with an expected lifetime of more than three years
- Business travel for personnel
- Travel to and from work by personnel
- Research and development activities

For additional information about system boundaries concerning waste, etc., see the General Programme Instructions.

7.1.2 Boundaries in Time

The life cycle inventory (LCI) data shall be representative for the time period for which the reference flow is taken. The temporal resolution of LCA data could be defined by TRLs:
For TRL 3/4, use the best temporal information/data available.

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For TRL 5/6/7, provide the most presentative (or empirical) temporal information/data for case study.

For TRL 8/9, provide case specific temporal information/data.

7.2 Cut-off rules

LCI data for a minimum of 95 % of total inflows to the core module shall be included. Inflows not included in the LCA shall be documented in the AgroCycle-LCA.

It is important to emphasise that – in most cases – all available data shall be used. Using cut-off rules should not give the perceptions of "hiding" information, but rather to facilitate the data collection for practitioners.
The detail of cut-off rules could be defined according to TRLs (as far as practically possible):

For TRL 3/4, cut-off rule for data is >75%

For TRL 5/6/7, cut-off rule for data is 85-95%

For TRL 8/9, cut-off rule for data is >95%

7.3 Allocation rules

Allocation rules must be defined for individual products when the manufacturing processes result in many kinds of products and where there is only aggregate information available about the total activity and emissions.

The following procedure shall be undertaken as necessary:

- Avoid allocation by collecting more product specific information that allows for a more detailed system description.
- If allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them.
    - Energy: energy allocation
    - Nutrient: N, P, K allocation (as appropriate to the case study)
    - Protein: protein allocation
- Where possible, allocation between different products and co-products shall be based on product mass
- Where physical relationships alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them e.g. economic value.

  The allocation procedure used should reflect the pedigree of the available data (i.e. a theoretically 'better' methods should not be used if it relies on poor pedigree data)

In case of economic allocation, the AGROCYCLE-LCA shall detail the reference values that is used. Any other allocation procedures based on physical or chemical characteristics must be specified in the AGROCYCLE-LCA report.

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7.4 Data quality rules

Specific data (also referred to as primary data and site-specific data) shall be used for the Core Module. Specific data are gathered from the valorization process and data from other parts of the life cycle traced to the specific value-added product system under study. Data with high spatial (with regional or country specification) and temporal resolution are required for social indicators in all processes within the system boundary. High temporal resolution is required for economic indicators in all processes within the system boundary.

For the electricity used in the process, there are two alternatives: the company buys the energy from the open market electricity mix or from a specific supplier with a defined mix. While in the first case the national electricity, mix can be adopted, in the second case a specific energy mix should be used. Electricity production impacts should be accounted for in this priority:

- RECS or guarantee of origin from supplier
- Electricity supplier's residual energy mix
- National mix/electricity mix on the actual market (preferably residual mix, otherwise national mix)

The electricity mix used shall be documented. The detail of electricity mix can be defined by TRLs:
For TRL 3/4, use best possible data, but can be of low pedigree.
For TRL 5/6/7, good pedigree data at least.
For TRL 8/9, high pedigree data specific to the technology, geography and time.

8. Upstream Module

8.1 System boundaries

As a minimum the processes listed in Section 6.1 shall be included in the upstream module but other processes not listed may also be included. All elementary flows at resource extraction shall be included, except for the flows that fall under the general 1% cut-off rule.

8.2 Data quality rules

As a general rule, specific data shall always be used if available. For the upstream module, specific feedstock characterisation data must be used.

Specific data should be employed for the following activities:

- Feedstock production
- Water consumption
- Fuel/energy consumption
- Waste generation
- Operations at the waste valorization production facility

8.2.1 Rules for using generic data

When using selected generic data, prescribed characteristics for precision, completeness and representativeness must be fulfilled and demonstrated, including but not limited to:

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- Reference year to be 'actual-if-possible', preferably being representative for at least 5 years
- Cut-off of at least 95% of both the energy, the mass, and the overall relevance of the flows
- Inventory data set should include all elementary flows that contribute to those impact categories defined in the scope
- Geographical representativeness of the inventory for the technology or product should, as a general principle, be better than ± 5 %.

8.2.2 Data quality declaration

The pedigree of all data should be assessed and reported following the TRL guidelines defined above.

9. Downstream Module

The processes listed in Section 6.3 shall be included in the downstream module. The downstream module shall be based on relevant scenarios for the geographical area in which the AGROCYCLE-LCA is valid.

9.1 Transportation from final Valorization process to an average retailer/distribution platform.

Transport of the value-added product to a customer shall, as a first option, be based on the actual transportation distances. As a second option, it can be calculated as the average distance of a product of that type transported with different means of transport or, if few transport data are available, it can be calculated as a fixed transport distance of 100 km (small truck), 1000 km (large truck) or 10,000 km (airplane) according to product type.

9.2 Use phase of value-added product

The use phase of the value-added product should not be included

9.3 Waste treatment of packaging waste

Scenarios for the waste treatment of packaging waste shall be defined in the AGROCYCLE-LCA. The information shall be technically and economically practicable, and compliant with current regulations.

10. Sustainability performance information

10.1 Use of resources

The consumption of natural resources and resources per declared unit shall be reported in the AGROCYCLE-LCA, divided into core, upstream and downstream module.
Input parameters, extracted resources:

- Non-renewable resources
  - Material resources
  - Energy resources (used for energy conversion purposes)
- Renewable resources

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- Material resources
- Energy resources (used for energy conversion purposes)

- Secondary resources
  - Material resources
  - Energy resources (used for energy conversion purposes)
- Recovered energy flows (such thermal) expressed in MJ
- Water use divided in:
  - Total amount of water
  - Direct amount of water used by the core process

The following requirements on the resource declaration also apply:

- all parameters for resource consumption shall be expressed in mass, with the exception of renewable energy resources associated with the generation of hydroelectric, wind electricity and solar energy, which shall be expressed in MJ;
- all parameters shall not be aggregated but reported separately. Resources which contribute less than 5 % in each category shall be included in the resources list as "other";
- nuclear power shall be reported among the non-renewable energy resources as kg of uranium calculated by converting the thermal energy (MJ) considering a 3rd generation reactor with an efficiency of 33 %.

10.2 Potential environmental impacts

The potential environmental impact per declared unit for the following environmental impact categories shall be reported in the AGROCYCLE-LCA, divided into core, upstream and downstream modules. The potential environmental impacts are grouped into three tiers, based on importance or impact relevance, practicality and complexity:

- **Tier 1** (indicators in yellow): most important or of global relevance. Should be included in any AgroCycle LCA as baseline indicators.
- **Tier 2** (indicators in green): Important indicators for circular economy, providing a broad picture of sustainability and performance of the supply chain in a circular economy context. Recommended to be included in the four case studies for AgroCycle deliverables.
- **Tier 3** (indicators in blue): optional indicators for a comprehensive sustainability assessment. Where data are available should be included in the four case studies for AgroCycle deliverables.

The potential midpoint environmental indicators are listed in Table 1. Other environmental indicators could be added into the Tier 3 category, according to characteristics of the waste valorization processes or products. Monetary valuations are recommended for aggregating different environmental impacts into total environmental impacts at the end point level.

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Table *1* Potential environmental indicators for AgroCycle

Mid-point level environmental issue	Indicator	Unit	Impact resolution
Global warming	Global warming potential (GWP, 100 years)	kg CO_2-eq	Global level
Acidification	Acidification potential (AP)	Kg SO_2-eq or m^2 UES	High spatial resolution
Eutrophication	Aquatic eutrophication potential (EP)	kg PO_4^{3-}-eq or kg NO_3-eq	High spatial resolution
	Terrestrial eutrophication potential (EP)	m^2 UES	High spatial resolution
Water use	Blue water consumption	m^3	High spatial resolution
Land use	Land occupation	m^2-years	High temporal and spatial resolution
Mineral resource depletion	Mineral extraction	MJ extra	Global level
Human toxicity	Human toxicity, non-carcinogens (HTP)	kg C_2H_3Cl-eq	High spatial resolution
	Human toxicity, carcinogens (HTP)	kg C_2H_3Cl-eq	High spatial resolution
Ozone layer depletion	Ozone layer depletion potential (ODP)	kg CFC-11-eq	Global level
Eco-toxicity	Fresh water eco-toxicity potential (ETP)	kg TEG-eq	High spatial resolution
	Marine water eco-toxicity potential (ETP)	kg TEG-eq	Global level
	Terrestrial eco-toxicity potential (ETP)	kg TEG-eq	High spatial resolution
Photohemical smog	Photochemical oxidation potential (POCP)	m^2*ppm*hours or kgC_2H_4-eq	High spatial resolution

10.2.1 Specifications for GWP calculations

Both emissions to the atmosphere and removals from the atmosphere shall be accounted for the assessment of the overall GHG emissions of the product being assessed. This assessment shall include the gases arising from both fossil and biogenic sources for all products, with the exception of human food and animal feed products. Emissions and removals of biogenic carbon shall be reported separately.

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Where some or all removed carbon will not be emitted to the atmosphere within the 100-year assessment period, the portion of carbon not emitted to the atmosphere during that period shall be treated as stored carbon. Following issues shall be taken into account:

- Carbon storage might arise where biogenic carbon forms part or all of a product (e.g. wood fibre in a table), or where atmospheric carbon is taken up by a product over its life cycle (e.g. cement).
- While forest management activities might result in additional carbon storage in managed forests through the retention of forest biomass.

The results with GHG emissions offset mechanism (e.g. biogenic carbon) shall be presented and compared with the results without GHG emissions offset mechanism in AGROCYCLE-LCA. Critical analysis should be carried out to investigate the contribution of offset mechanism in overall GHG emission.

10.3 Potential Social impacts

The potential social impact per declared unit selected from the social impact categories of UNEP-SETAC Social LCA Guideline shall be reported in the AGROCYCLE-LCA, divided into core, upstream and downstream modules. The potential social impacts are grouped into three tiers, based on importance or impact relevance, practicality and complexity:

- Tier 1 (indicators in yellow): most important or of global relevance. Should be included in any AgroCycle LCA as baseline indicators.
- Tier 2 (indicators in green): Important indicators for circular economy, providing a broad picture of sustainability and performance of the supply chain in a circular economy context. Recommended to be included in the four case studies for AgroCycle deliverables.
- Tier 3 (indicators in blue): optional indicators for a comprehensive sustainability assessment. Where data are available should be included in the four case studies for AgroCycle deliverables.

The potential social indicators are listed in Table 2. Other social indicators could be added to Tier 3 category, according to characteristics of the waste valorization processes or products. Survey of relevant stakeholders is recommended for weighting different social impacts in each stakeholder category for end point results.

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Table *2* Potential social indicators for AgroCycle

Stakeholder category	Mid-point level social issue	Indicator	Unit	Impact resolution
Worker	Fair wage	Cumulative risk of fair wage in supply chain	Semi-quantitative results	High temporal and spatial resolution
Worker	Health and safety	Cumulative fatality rate (injury rate) in supply chain	Number of case	High spatial resolution
Worker	Working time	Cumulative working time in supply chain	Second (s)	High spatial resolution
Local community	Public living condition	Avoided environmental cost on human health in supply chain	Euro $_{2003}$	High spatial resolution
Local community	Provision of employment	Created employment opportunity	Number of job	High spatial resolution
Worker	Child labour	Cumulative child labour in supply chain	Labour unit	High spatial resolution
Worker	Forced labour	Cumulative forced labour in supply chain	Labour unit	High spatial resolution
Society	Contribution to economy	Total added value to economy in macro scale	Semi-quantitative results	High temporal and spatial resolution
Society	Technology development	Change of production efficiency	Semi-quantitative results	High spatial resolution
Value chain	Promoting social responsibility	Waste reused or recycled	Kg waste	High spatial resolution
Local community	Resource and energy security	Avoided resource and energy	kg resource or MJ energy	High temporal and spatial resolution

10.4 Potential Economic impacts

The potential economic impact per declared unit shall be reported in the AGROCYCLE-LCA, divided into core, upstream and downstream modules. The potential economic impacts are grouped into three tiers, based on importance or impact relevance, practicality and complexity:

- Tier 1 (indicators in yellow): most important or of global relevance. Should be included in any AgroCycle LCA as baseline indicators.
- Tier 2 (indicators in green): Important indicators for circular economy, providing a

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broad picture of sustainability and performance of the supply chain in a circular economy context. Recommended to be included in the four case studies for AgroCycle deliverables.

- Tier 3 (indicators in blue): optional indicators for a comprehensive sustainability assessment. Where data are available should be included in the four case studies for AgroCycle deliverables.

The potential economic indicators are listed in Table 3. Other economic indicators could be added into Tier 3 category, according to characteristics of the waste valorization processes or products. Monetary aggregation should be used for reporting end point results, depending on the nature of the economic assessment.

Table *3* Potential economic indicators for AgroCycle

Economic issue	Indicator	Unit	Impact resolution
Production Cost	Labour cost	€	High temporal and spatial resolution
	Transportation cost	€	High temporal and spatial resolution
	Equipment cost	€	High temporal and spatial resolution
	Electricity and fuel cost	€	High temporal and spatial resolution
	waste collection and material cost	€	High temporal and spatial resolution
	Maintenance cost	€	High temporal and spatial resolution
	Soft cost (design fee, permit fee…)	€	High temporal and spatial resolution
Profitability	Net income per function unit	€	High temporal and spatial resolution
Efficiency of value creation from valorization	Net value added per kg waste	€/kg	High temporal and spatial resolution

10.5 Waste production

When the amount of waste has to be declared, the following information shall be reported:

- Hazardous waste, in kg (as defined by regional directives)
- Non-hazardous waste, in kg

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10.6 Other indicators

The following indicators per declared unit could also be reported in the AGROCYCLE-LCA, divided into core, upstream and downstream module:

- Material circularity indicator
- Energy recovery indicator
- Others relevant to the goal of the study

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