Milestone MS14
LCA and LCC protocol guidance

August 2021

PUBLIC

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This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945098.

Project acronym PREDIS	Project title PRE-DISposal management of radioactive waste		Grant agreement No. 945098
Milestone No. MS14	Milestone title LCA protocol guidance		
WP No 2	Date version 16.08.2021		Due date M12
Lead beneficiary CEA			
Main author Laurence Stamford (UoM)	Reviewed by Anthony Banford (NNL); Maxime Fournier (CEA)	Accepted by Maria Oksa (VTT Coordinator)	
Contributing author(s)			Pages 11

Abstract

Milestone M2.11 is part of Sub-task T2.5.1: *Definition of environmental, process and economic evaluation protocol for the project based on life cycle assessment (LCA) and life cycle costing (LCC)*. The milestone marks the culmination of work to develop a project-wide protocol for the evaluation of processes including the incorporation of LCA and LCC. This protocol draws on international standards such as ISO 14040/41, standardised Europe-wide approaches such as the PEF guides and ILCD; and prior sustainability assessment literature in the nuclear, energy and waste sectors and in innovation research. The protocol has been developed iteratively via consultation with other PREDIS technical work packages (WPs 4-7).

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Acknowledgement
This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945098.

1 Milestone Description

Milestone M2.1, associated with Work Package 2 (Strategic Implementation), Task 2.5 (Cross Work Package Strategic Assessment) has been completed on 16.08.2021.

The justification for readiness in the Grant Agreement Description of Action includes verification by the EUG. However, this has not yet occurred. This document will be made available to the EUG in Autumn 2021 to solicit feedback. Before then, the protocol and this document have been reviewed by the WP leaders and the project management team. The readiness of the milestone was reviewed and agreed upon by Anthony Banford (NNL) as WP2 leader and Maxime Fournier (CEA) as Task 2.5 leader.

2 Assessment protocol

This protocol outlines how environmental life cycle assessment (LCA) and life cycle costing (LCC) will be undertaken in PREDIS. The main aims of this work are to estimate the impacts of processes developed within PREDIS, compare them to base case waste treatment options available prior to PREDIS, and provide insights for the strategic research direction of future treatment development.

LCA is an environmental sustainability tool that applies life cycle thinking in order to assess the consequences of human activities. Broadly speaking, LCA involves:

1. quantification of environmental burdens of a product, process or activity via assessment of the energy and materials used and wastes released to the environment;
2. quantification of environmental impacts (i.e. translating the above burdens into potential impacts); and
3. identification of opportunities for environmental improvements along the life cycle via the identification of 'hot spots'.

LCA is a well-established technique with a wealth of existing literature demonstrating its use. It is standardised via ISO 14040 and 14044 [1, 2], in which four key phases are identified, as outlined in Figure 1.

- **PREDIS T2.5 will align with ISO 14040/44.**

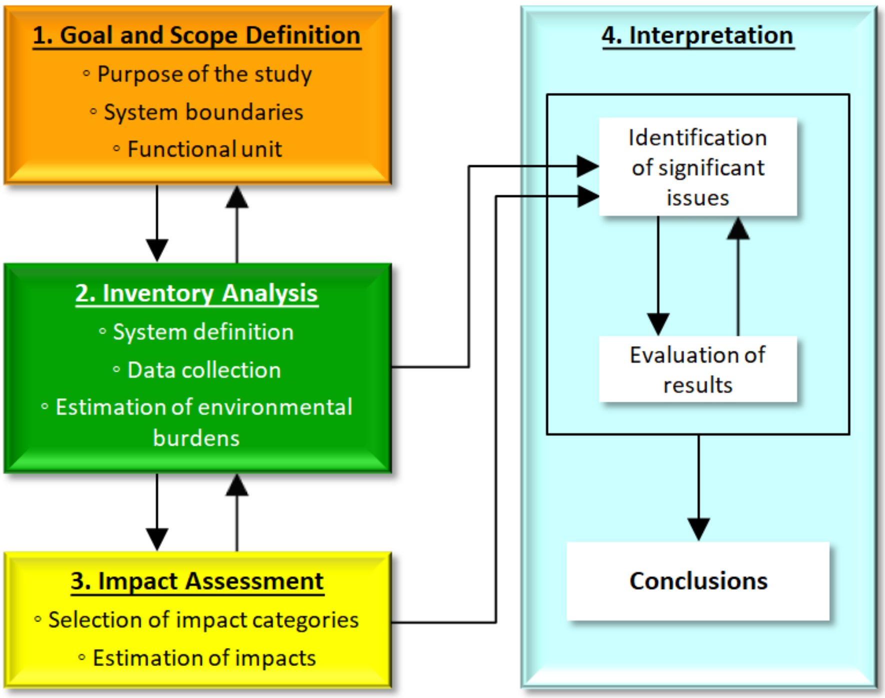

Figure 1 The four phases of life cycle assessment as defined in ISO 14044

As outlined in the figure, the Goal and Scope Definition phase involves defining the purpose of the study, the system boundaries and the functional unit.

- **The default goal and scope in PREDIS T2.5 will be cradle to grave, starting at the receipt of waste to be treated (from waste generator organisations) and ending at final geological disposal (typically with a waste management organisation). This will require review of data on final repositories (i.e. outside the scope of PREDIS technical work packages) to be conducted within WP2 in order to ensure methodological robustness.**
- **The functional unit will be defined on a case-by-case basis, based on the specific technologies and scopes of each work package.**

The Inventory Analysis phase of LCA is concerned with the collection of technical data, such as the mass and energy flows throughout the system's life cycle, and the estimation of flows to, and from, the environment. Typically this is achieved with some reliance on existing databases or literature to provide data for background systems (e.g. data on the environmental burdens associated with material inputs). In Europe, for instance, the Swiss non-profit 'ecoinvent' database [3] is the most widely used and accepted life cycle inventory database. Many other similar databases exist, such as the U.S. LCI Database managed by NREL [4].

- **PREDIS T2.5 will use Ecoinvent database for background inventory data where preferable data do not exist. (See section 3 for an outline of data sources.)**

The third phase of LCA, Impact Assessment, uses environmental impact coefficients, often referred to as characterisation factors, to estimate the potential environmental impacts caused by the burdens identified during the Inventory Analysis phase. The exact list of indicators generated by an LCA depends on the impact assessment method adopted, and a variety of options exists. Much of the existing literature has used the CML method [5] but there is increasing consensus that this is now outdated. Alternatives include IMPACT2002+ [6], TRACI [7, 8], ILCD [9] and ReCiPe [10, 11] (see Table A1 in the appendix for the impact categories they consider). Of these options, ReCiPe is often seen as the state-of-the-art and there is some evidence to suggest that it is the most widely used method, although a plurality is evident in the community [12]. The standard life cycle impact assessment methods have a relatively simplistic approach to radiological impacts, leading to recent work which has developed and recommended new methods – known as CGM and UCrad – to be used in the context of nuclear power and waste management activities [13, 14].

- **PREDIS T2.5 will adopt ReCiPe as the default impact assessment methodology, providing information on all included impact categories. The UCrad method for radiological impact will be considered additionally, alongside other approaches to radiological impact assessment, and potentially including development of new approaches.**

2.1 Allocation of impacts

Industrial processes are often multi-output systems with various co-products, therefore there is a need to allocate impacts between these co-products. According to ISO 14040/14044, allocation should be avoided where possible by either subdividing the system under study or by **system expansion**. The latter is often seen to be the preferable option and, in its simplest form, involves crediting the system with the avoided burdens incurred by the co-products.

If system expansion cannot be performed — for instance if the co-product has no equivalent — then **physical** or **economic allocation** can be used. In such cases the impacts of the system are allocated to each co-product based on mass, energy content or economic value.

- **Where necessary, allocation will be tackled using system expansion, with other allocation approaches investigated as part of sensitivity analysis.**

2.2 Life cycle costing

Life cycle costing (LCC) is not standardised in the same way as LCA, although it shares a common aim of accounting for (economic) impacts across the entire life cycle. A general methodology exists for LCC [15] based on work by the Society of Environmental Toxicology and Chemistry (SETAC), a leading developer of LCA. This methodology mirrors that of the LCA cradle-to-grave approach in that LCC should include capital costs, fixed operating costs, variable operating costs, waste management and recycling costs, end of life costs and transport costs.

Various metrics are permissible within LCC, based on discounted or non-discounted costs presented per life cycle stage, net present value, annualised costs and value added [16].

- **LCC models within PREDIS will align with their corresponding LCA models in terms of system boundary, system specification and functional unit, to maintain internal consistency.**
- **The choice of LCC metrics will be determined on a case-by-case basis, based on the specific technologies and scopes of each work package.**
- **Cost data will be sourced and estimated by researchers in Task 2.5 and in collaboration with technical work packages 4-7 wherever possible.**

3 Inputs from partners

An LCA model can be separated into 'foreground' and 'background' systems, as outlined below. The PREDIS partners will be asked for information on the foreground system only.

3.1 The 'foreground' system

The foreground system of an LCA model is the actual system and technologies under study. This may be described by a process diagram by engineers/scientists working on the system. In the context of PREDIS, it could include, for instance, the materials required to produce geopolymers and the processes undertaken to apply them to waste streams.

For the foreground system, T2.5 will rely on information from project partners (see section 'Data collection').

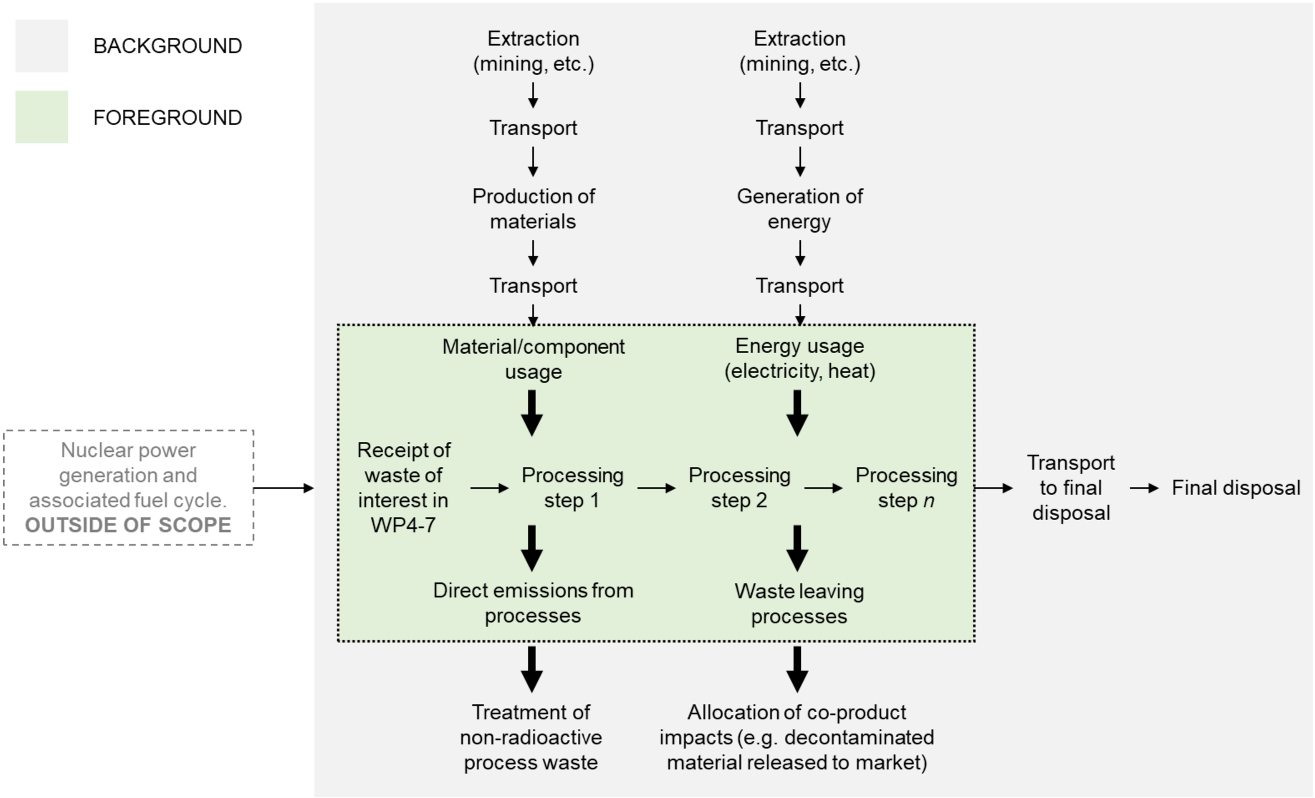

Figure 2 - system foreground and background

3.2 The ‘background’ system

The background system describes flows of materials/energy that are secondary to the foreground system. For instance, the mining of minerals for geopolymer production, the extraction of metal ores and the production of components required to incorporate waste streams into geopolymers.

For the background system, T2.5 LCA practitioners will source data from databases and literature, requiring minimal or no input from PREDIS project partners.

4 Data collection

The LCA work will rely primarily on input from PREDIS partners in the technical work packages (WP4-7) for the foreground system. This can take the form of **process flow diagrams**, or information gathered through the **data collection template** shown in Appendix B and available as an Excel file from the author of this document. The template is generic and may be adapted to any specific processes being described by PREDIS project partners.

The partners are not expected to be able to complete every part of the data collection template. **Indicative values, ranges, and explanatory comments** would be a strong starting point.

As the timelines and technologies of interest are different for each WP, the anticipated approach is to start with a ‘**base case**’ that outlines the treatment of wastes without PREDIS pre-disposal approaches, and then to progress to several **scenarios for different PREDIS pre-disposal case studies** which can be developed continuously according to the differing progression timelines of each WP. This will help end users to make decisions around the technical advances developed within PREDIS, using quantitative environmental and economic criteria.

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6 Appendix A – LCA impact assessment methods

Table A1 Impact categories in three of the most widely-adopted LCA impact assessment methods, arranged according to their equivalence

ReCiPe	ILCD	CML
Global warming	Climate change	Global warming
Terrestrial acidification	Acidification	Acidification
Freshwater eutrophication	Eutrophication	Eutrophication
Stratospheric ozone depletion	Ozone depletion	Ozone layer depletion
Tropospheric ozone formation (humans)	Photochemical ozone formation	Photochemical oxidant creation
Tropospheric ozone formation (ecosystems)		
Human toxicity (cancer)	Human toxicity	Human toxicity
Human toxicity (non-cancer)		
Freshwater ecotoxicity	Ecotoxicity	Freshwater aquatic ecotoxicity
Marine ecotoxicity		Marine aquatic ecotoxicity
Terrestrial ecotoxicity		Terrestrial ecotoxicity
Mineral resources	Resource depletion	Depletion of abiotic resources, elements
Fossil resources		Depletion of abiotic resources, fossil fuels
Particulate matter	Respiratory inorganics / particulate matter	
Ionising radiation	Ionising radiation	
Land use/transformation	Land use	
Water use		

7 Appendix B – data collection template

Instructions

Please complete this form, providing as much information as possible, with reference to one unit of product or one batch / production run. Please ensure that the amounts given in column B are internally consistent, i.e. they should be expressed per the same unit of assessment. Please provide comments in the 'comments/clarifications' cells where appropriate.

Yellow highlighted cells depict data gaps

1. Raw materials

Raw material	Amount (kg)		Comments / clarifications	Questions
E.g. type of component				Please provide a description of raw materials, as well as the quantities used.
E.g. water				

2. Packaging the raw materials arrive in

Raw material	Amount (kg)	Type (e.g. HDPE, PP, glass, cardboard)	Comments / clarifications	Questions	Disposal of packaging (landfill/incineration /recycling/reuse)
				What are your raw materials packaged in when they arrive?	

3. Transport of materials to plant

Raw material	Mode (e.g. pipeline, road, rail, water)	Origin (specific city or country)	Comments / clarifications	Questions
				How does each raw material arrive at the site? From where?

4. Energy consumption				
Energy	**Amount (e.g. in KWh, MJ)**	**Units**	**Comments / clarifications**	**Questions**
E.g. electricity				How much energy do you use?
E.g. gas				

5. Emissions/waste coming directly from your process					
5a. Wastewater					
Type	**Amount (kg)**	**(Treated on site or sent to off site treatment)**	**Comments / clarifications**	**Questions**	
E.g. wastewater from washing equipment				How much wastewater is produced and how is it treated?	
5b. Solid waste					
Type of waste	**Amount (kg)**	**Disposal mode (landfill/incineration)**	**Comments / clarifications**	**Questions**	**Transport mode (e.g. road, rail, water)**
				How much solid waste is produced (excluding the radioactive waste which is the main product) and how is it disposed of?	
5c. Air emissions					
Type	**Amount (kg)**		**Comments / clarifications**	**Questions**	
E.g. NOx				Please provide data for emissions to air, if applicable.	

6. Products				
6- Products	**Amount (kg)**		**Comments / clarifications**	**Questions**
				What is your main output? Please also add byproducts, including what happens to them.

7. Packaging of products				
Type (e.g. HDPE, PP, glass, cardboard)	**Amount (kg)**		**Comments / clarifications**	**Questions**
				Please provide packaging data for the products, if applicable.