ReHydro

Demonstration of Sustainable Hydropower Refurbishment

D5.3 Goal and scope of LCA

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Executive Summary

This deliverable presents the goal and scope of the Life Cycle Assessment (LCA) study. Based on the discussions with Compagnie Nationale du Rhône (CNR), two retrofitting actions were highlighted: the construction of a fish ladder and the construction of a Small Hydro Power Plant (SHPP). The fish ladder will be built in the two studied scenarios as it is requested by French regulation whereas the SHPP will be considered in only one scenario. In scenario two, the SHPP will not be built, and the producible loss is considered to be compensated for by another source of electricity (various sensitivity analysis on the nature of the electricity will be carried out). The LCA results will be presented through the most relevant environmental indicators of the EF 3.1 impact assessment method. Those indicators will be selected through a normalization and weighting process.

List of acronyms

BOM Bill of materials

CNR Compagnie Nationale du Rhône

CTU Comparative toxic unit

GHG Greenhouse gases

HPP Hydropower plant

IPCC Intergovernmental Panel on Climate Change

LCA Life cycle assessment

O&M Operation and maintenance

PEF Product environmental footprint

SHPP Small hydropower plant

1 Objective of the deliverable

Life cycle assessment (LCA) is a standardized methodology (ISO 14 040 and ISO 14 044) to estimate the environmental impacts of products and services through their life cycle. This approach can therefore be applied to hydropower plants and even to the refurbishment scenarios of hydropower plants. This deliverable aims at presenting the goal and scope of the LCA study that will be carried out in the context of the ReHydro project.

2 Life cycle assessment applied to hydropower plants

2.1 Presentation of the LCA methodology

LCA is standardized by ISO 14 040 and 14 044 and is divided into four steps as presented in Figure 1:

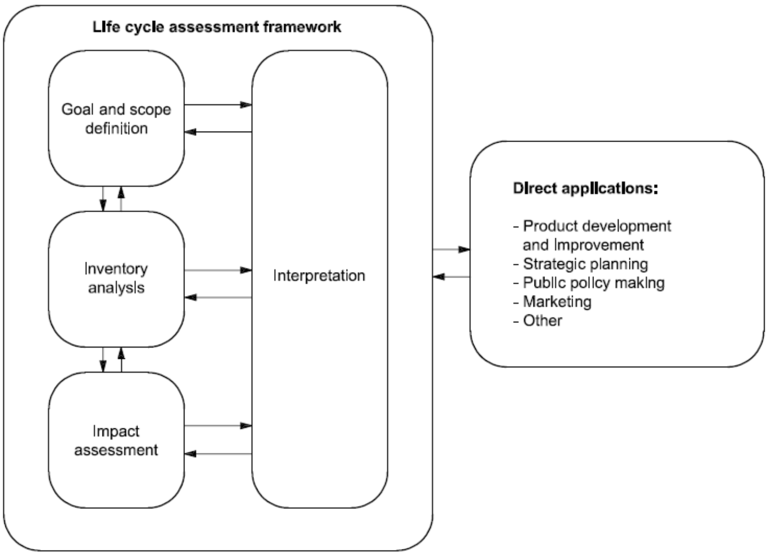

Figure 1. Stages of the LCA methodology (ISO 14 040)

These four steps are:

- Goal and scope definition: in this first stage, the system(s) studied are described, the functional unit is presented alongside with the system boundaries in accordance with the objectives of the study
- Inventory analysis: this step aims at collecting the data associated to the scope of the study previously defined. The collect consists in gathering all the Bills of Materials (BOM), the amount of energy needed, the water consumption and the emissions in the air, water and soils of the different steps of our product life cycle
- Impact assessment: the collected flows are modelled in an LCA software then converted into impacts through characterization factors to obtain environmental indicators (climate change, resource depletion, water use,). Contrary to the carbon footprint methodology that only focuses on GHG emissions (i.e. climate change indicator), LCA is muti-criteria and encompasses various environmental indicators like climate change but also resource depletion or human toxicity
- Interpretation: the results of the LCA study are analysed, the most contributing stages, processes and flows are highlighted, conclusions are drawn alongside with recommendations and limitations. The interpretation should be consistent with the objective of the study, the collected data and the impact assessment carried out

2.2 LCA applied to hydropower plants

The LCA methodology has been applied to various hydropower plants (HPPs). A review of those studies was carried out in an article published in September 2025 (Luangphon, et al., 2025). The life cycle of HPPs can be divided into five stages:

- Preparation stage: site clearing and construction of infrastructures like road to access the HPP
- Transportation phase: transport of all the materials needed for the construction or disposal of the excavated materials during the site clearing
- Construction phase: civil engineering of the structure and installation of electromechanical systems. The manufacturing and the transportation of these systems are also integrated.
- Operation and Maintenance (O&M): energy consumption for daily operations and regular maintenance (including the electromechanical equipment). Methane emissions from the reservoir are a growing concern in terms of climate change impacts and needs to be accounted for as operational emissions.
- Decommissioning: removal of the dam and recycling of valuable materials (steel for example). However, this step is hard to assess as HPPs have long lifespan.

LCA studies agree that the main contribution to the environmental impacts of HPPs is the construction phase due to the manufacturing of steel and concrete.

As far as we know, there has been no specific LCA work done on the refurbishment of HPPs.

3 LCA study in ReHydro

In the context of the ReHydro project, the objective is to assess the environmental impacts of refurbishments scenarios of a HPP and more specifically from a run-of-river plant (also called diversion plant) that differs from a reservoir type (also called impoundment plants) or pumped storage plants (Luangphon, et al., 2025). More precisely, the case study will be carried out on a plant of CNR (Compagnie Nationale du Rhône), one of the consortium partners.

Various discussions took place with CNR to understand their installations and the potential actions that could occur at the time of the renewal of the current concession.

The installation of these systems is represented in the following figure:

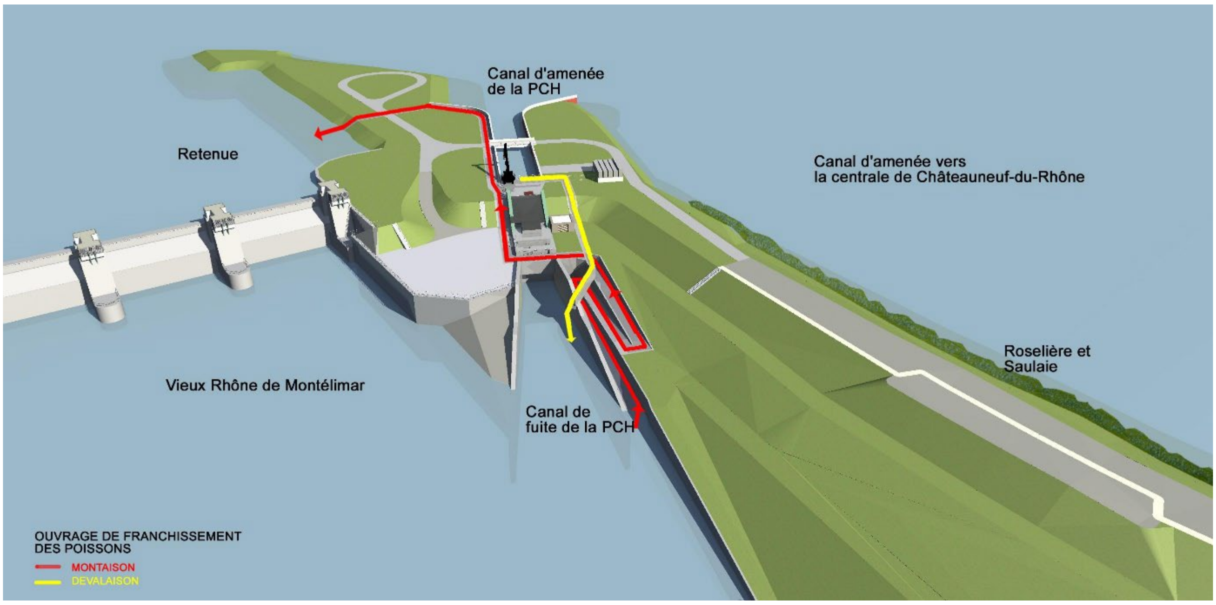

Figure 2. standard installation of CNR on the Rhône River with SHPP and fish ladder – Châteauneuf-du-Rhône dam.

On the left of the installation ("Old Rhône side"), a dam has been built which allows the environmental flow to pass through (i.e. the minimum amount of water dedicated to ecosystemic services). The right part of the figure corresponds to the amount of water that will be turbined to produce electricity in the hydropower plant. In 2014, the French regulation imposed to increase the environmental flow. To compensate this loss of daily producible, a solution is to build a SHPP. The SHPP derives a certain amount of water going to the hydropower plant, turbines it and discharge the water into the "Old Rhône side" to respect the regulation on the environmental flow. In Figure 2, the SHPP corresponds to the structure in the middle between the two branches of the river.

Moreover, a fish ladder can be integrated into the SHPP to allow the passage of fish species either to go up (in red) or to go down (in yellow). This fish ladder can be also independent from the SHPP.

In conclusion, two main retrofitting actions were highlighted:

- The construction of a new fish ladder to ease the passage of different fish species. Note that this construction is mandatory through a new French regulation[1]
- The construction of a Small Hydropower Power Plant (SHPP) to compensate the producible loss due to the increase of the environmental flow

3.1 Research question

Based on the discussions with CNR, two main questions arose:

- The impacts of the construction of the fish ladder: what are the environmental impacts of this kind of system?
- The impacts of the decrease of electricity production at the main powerplant: is it better to build a SHPP to compensate part the losses? Or is it better to compensate with other already existing production technologies such as wind or PV or the use of fossil-based electricity? We don't consider that CNR will have to invest in a dedicated wind farm for example. We assume that the compensating technology are already built.

The LCA study aims at providing recommendations for these different questions.

3.2 Functional unit

In the LCA methodology, the functional unit of a product or a service is the quantified description of the function(s) that the system fulfils. The main purpose of a HPP is to produce electricity but also in our case a second function seems important to take into account: the possibility of letting the fish species go through. Therefore, the functional unit of this study is

"Produce 50 GWh[2] of electricity per year to compensate producible loss and allow the migration of fish species going through the installation of a fish ladder in the Rhône River"

The 50 GWh corresponds to the yearly production of the SHPP. In the scenario where no SHPP is built, these 50 GWh will be produced through an alternative source of electricity production.

3.3 Scenario definitions

In this LCA study, 2 scenarios will be modelled:

- Scenario 1: the fish ladder is installed alongside with the construction of the SHPP. In this scenario, the construction works for both installations can be carried out at the same time potentially decreasing the overall impacts thanks to this synergy
- Scenario 2: only the fish ladder is installed. To maintain the level of production, more production of an already existing electricity installation is needed. Inside this scenario, various alternatives are possible (PV or fuel oil-based asset for example)

3.4 System boundaries

All operations before the renewal of the concession are out of the scope of the study: the site preparation, the construction of the initial HPP or of the dam; their operation or their

[1] French law n° 2022-271 from February 28th 2022
[2] This value is a rough estimate and could be changed in the future.

maintenance. Only construction and operations carried out for refurbishment purposes are integrated to the studied systems as described in Figure 3 :

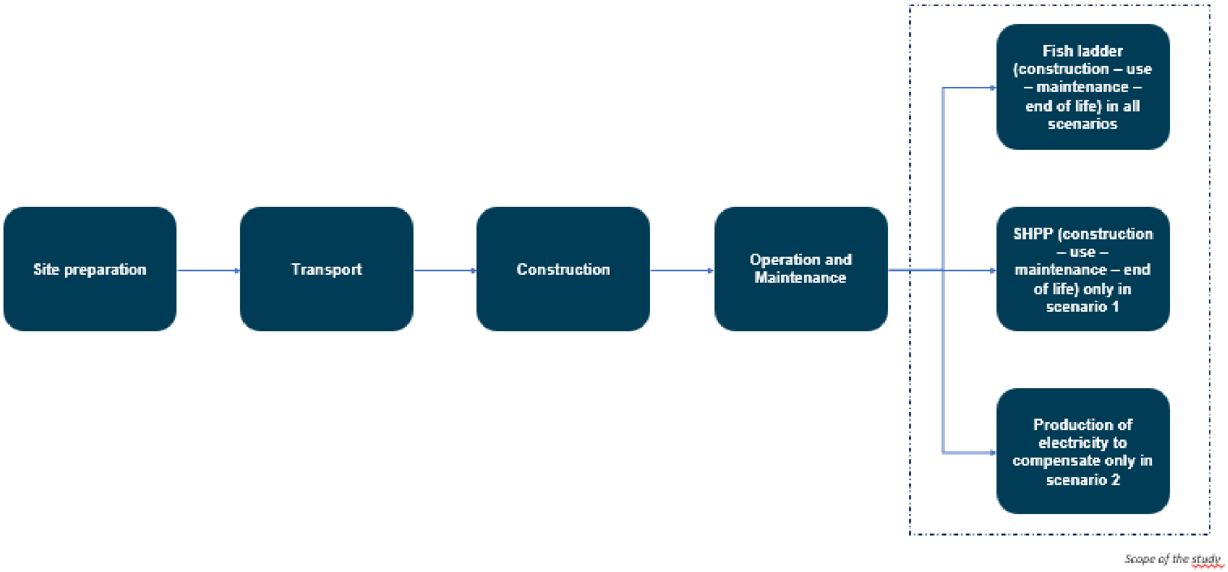

Figure 3. Scope of the LCA study.

In scenario 2, the increased environmental flow will transit through the dam gates at low opening, potentially leading to premature wear (i.e. more maintenance). The additional heavy maintenance on the gates could be added in the LCA study in case we have access to quantifiable data on the maintenance.

In scenario, the increased environmental flow will entirely transit through the SHPP to produce electricity.

For both scenarios, end-of-life hypothesis will be taken following the more probable end-of-life pathways for the fish ladder and the SHPP in scenario one. A "Cut-off" approach will probably be applied meaning that all impacts of materials going to disposal or incinerated without energy recovery will be allocated to our system.

3.5 Impact assessment methodology and indicators

In LCA, impact assessment methods are used to translate the modelled flows/processes into environmental indicators. For this study, the Environmental Footprint method version 3.1 (Bassi, et al., 2023) will be used. It is supported by the European Commission as the method of choice for PEF studies and includes the latest IPCC characterization factors. Therefore, it is considered as one of the most consistent methods at the time of the redaction of this deliverable. If a more consistent approach or an update of this method is published in the future months, this choice could change.

This methodology integrates 16 indicators as listed in Table 1:

Table 1. List of indicators available in the EF 3.1 method.

Indicator	Unit
Acidification	mol H+ eq
Climate change	kg CO_2 eq
Ecotoxicity, freshwater	CTUe
Particulate matter	disease incidences
Eutrophication, marine	kg N eq
Eutrophication, freshwater	kg P eq
Eutrophication, terrestrial	mol N eq
Human toxicity, cancer	CTUh
Human toxicity, non-cancer	CTUh
Ionising radiation	k Bq U-235 eq
Land use	Pt
Ozone depletion	kg CFC 11 eq
Photochemical ozone formation	kg NMVOC eq
Resource use, fossils	MJ
Resources use, minerals and metals	kg Sb eq
Water use	m^3 deprived

To make the results more accessible, a selection of the most relevant indicators is necessary. This selection is possible through a combination of normalization and weighting:

- Normalization: the results are expressed upon a reference value (i.e. the annual impacts of an inhabitant of the world)
- Weighting: the normalized impacts are ranked based on the importance of impacts according to a panel expertise

This first approach for selecting indicators can be completed with our intern expertise (in the case where some indicators are not highlighted through the normalization and weighting approach). Here are some indicators available in EF 3.1 that are often used in our internal studies:

- Climate change: impacts associated with the emissions of greenhouse gases
- Particulate matter: impacts related to air pollution from particulates emitted by construction vehicles for example
- Land use: occupation of the soil area that can be relevant as construction works are involved in our systems
- Resource use, fossils: indicator that accounts for the amount of fossil energies used in our different scenarios
- Resource use, minerals and metals: depletion of metallic and non-metallic materials

4 Conclusions

In the context of the ReHydro project, an LCA study should be carried out on the refurbishment scenarios possible for an HPP. Based on the discussions with CNR, two research questions arose: the environmental impacts of the construction of a fish ladder and the management of the decrease of the producible. In a LCA study, the definition of the goal and scope is the first step. It encompasses the definition of the scenarios, the scope of the study or the selection of the environmental indicators. Next step is to collect the inventories related to these scenarios to model them.

5 References

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