Final definition of the impact categories and indicator for the E-LCA and S-LCA

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Revision History

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Name	Institute	Date
Darío CORTÉS, Sara MARTÍNEZ	Aragon Hydrogen Foundation	27 June 2022
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1. Introduction

The Hystories project aims to address the main technical feasibility issues of large-scale underground storage of pure hydrogen in aquifers or depleted fields, and will provide market, societal and environmental information on the deployment and exploitation of underground hydrogen storage in Europe, considering the three types of underground hydrogen techniques (the mature salt caverns as well as aquifers and depleted fields). The Work Package 6 (WP6) assesses the economic feasibility, environmental and social sustainability of several future aquifer or depleted field sites for pure hydrogen storage. In particular, tasks 6.2 and 6.3 focus on defining goal and scope of potential large-scale underground hydrogen storages to perform both the environmental and social Life Cycle Assessment (LCA). The results of both LCAs will be useful and indispensable for defining the implementation plan for underground renewable hydrogen storage in the EU by 2050 (WP9).

The objective of this report is to present the preliminary definition of goal and scope of the large-scale hydrogen underground storages, including aspects such as the definition of the functional unit and system boundaries, and the selection of impact categories and indicators for both the Environmental-Life Cycle Assessment (E-LCA) and Social-Life Cycle Assessment (S-LCA). This preliminary goal and scope definition was agreed upon after in-depth discussions between the consortium and industrial parties from the Advisory Board and is based on data provided by the consortium partner and Hystories project’s coordinator, namely Geostock. These preliminary descriptions are relevant to define the systems to be analyzed and thus to carry out the environmental and social performance assess.

This report is organized in 5 chapters. The first one presents the introduction of this report. Chapter 2 describes the main characteristics of large-scale underground storages of H_2 selected, Chapter 3 describes the LCA methodology applied, Chapter 4 defines the goal and scope of large-scale H_2 underground storages, including the impact categories and indicators selected for both E-LCA and S-LCA. Finally, Chapter 5 lists the literature referred to in the report.

2. Underground hydrogen storage systems description

The large-scale hydrogen underground storage systems selected to carry out the E-LCA and S-LCA were a salt cavern storage site and a porous media storage site. The main features of each storage site are shown in Table 1 and were provided by Geostock. Both underground storages were assumed to be located in France and guarantee a quality of H_2 stored of 99.93%. Concerning the salt cavern storage site, the site comprises 8 caverns, the free gas volume is 380,000 m^3 per cavern, with a casing shoe depth of 1,000 m, a pressure range of 70-180 bar and 8 wells/caverns per site, resulting in a working gas capacity of 250 MSm^3, maximum injection and withdrawal rates of 22.32 MSm^3/d and performing three annual gas injection/withdrawal cycles. Regarding the porous media, it operates in a pressure range of 60-130 bar with 550 MSm^3 of working gas, has an injection and withdrawal rate of up to 8.25 MSm^3/d of H_2 and only one gas turnover can be performed per year. 24 wells were drilled for production and 6 additional wells for monitoring of the storage. More details about the development and operation of these underground storage technologies can be found in Hystories report *D7.1-1 - Conceptual Design of salt cavern and porous media underground storage site*.

Table 1: Main features considered of the underground hydrogen storages. From Hystories report D7.1-1

Feature	Salt cavern	Porous media
Number of salt cavern/porous reservoir per storage site	8	1
Free gas volume per cavern (m^3)	380,000	-
Storage site working gas (MSm^3)	250	550
Maximum site withdrawal flowrate (MSm^3/d [a])	22.32	8.25
Withdrawal-to-injection flowrate ratio	2	2
Number of wells	8	24 + 6
Cycles per year [b]	3	1
Cavern height (m)	155	-
Quality of H2 (%)	99.93	99.93
Pressure range (bar)	70-180	60-130
Temperature range (ºC)	40-60	40-60
Total H2 stored [c] (tonne/year)	68,180	50,000

[a] MSm^3/day: Million standard cubic metre (at 15 ºC, 1.01325 bara) per day

[b] Gas injection/withdrawal cycles based on business needs and storage operating strategy

[c] Considering a H_2 standard volume per kilogram of 11 MSm^3/kg

3. Methodology

The E-LCA and S-LCA are both based on the ISO 14040 framework (ISO, 2006a, 2006b). Therefore, although some aspects differ, both assessments follow the LCA methodology (focused on environmental impacts) and are made in a similar way and in accordance, since the initial phases for the analysis design and configuration are the same. LCA methodology is described in the following section.

3.1. Life Cycle Assessment

LCA is a standardized methodology that compiles and assesses the environmental aspects and impacts of a product or service throughout its life cycle (ISO, 2006a, 2006b). The life cycle may encompass extraction and processing of raw materials, production, distribution, use, maintenance, and eventual reuse, recycling or disposal at end-of-life. LCA is generally considered the most appropriate methodology for estimating the environmental impacts of products or services since it addresses both their entire life cycle and the full range of environmental loads (Zamagni, 2009). The advantages of a life cycle approach to address sustainability are well known and relate to shifting problems avoidance, for example, from one life cycle stage to another, from one geographic area to another and from one environmental element to another (e.g. from air to water).

Figure 1 shows the four phases of the LCA (ISO, 2006): (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation. This framework allows for iterative procedures among phases. As the assessment develops, data limitations and new insights or stakeholder views can lead to a redefinition of the study focus, objectives, impact categories or indicators.

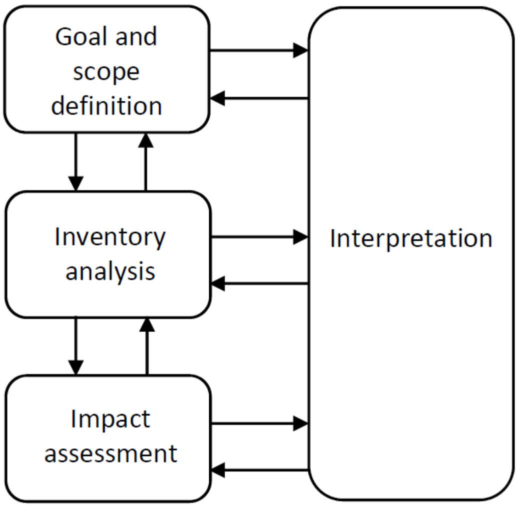

Figure 1: LCA structure

The goal and scope definition mainly involves aspects such as:

- Definition of the goal, including, the intended application, the reasons for accomplishing the study and the target audience;
- Definition of the system boundaries, i.e., the unit processes along the life cycle to be included in the analysis;
- Definition of the functional unit, which is the reference unit in relation to which the inventory and impact indicators are expressed;
- Definition of the initial data quality requirements;
- Selection of impact categories and respective methods for impact quantification.

The inventory analysis encompasses data collection for the processes previously identified within the system boundaries. These data comprise environmental aspects such as consumption of raw and auxiliary materials and energy, as well as emissions to air, water and soil and solid waste generation. The inventory analysis also includes calculation procedures so that the data collected for each process are summed up and related to the functional unit.

During the impact assessment, the inventory data are processed in terms of their environmental impacts previously selected in the scope. This phase involves three compulsory parts, as follows:

- Selection of impact categories, category indicators, and characterization models; there are currently several models available that include impact categories such as climate change, acidification, eutrophication, and resource depletion, among others;
- Classification, where the inventory parameters are assigned to specific impact categories;
- Characterisation, where equivalency between inventory parameters within each impact category is done considering the cause-effect chain (environmental mechanisms) by means of so-called characterisation factors, resulting in an indicator for each impact category.

The impact assessment phase may also include the following optional parts:

- Normalisation, where the results from the characterisation are compared to a reference situation that could be the total impacts of a country or a region, for each impact category;
- Grouping, which consists of sorting and possibly ranking the impact categories;
- Weighting, where the indicator results of the different environmental impacts are weighted relative to each other by using numerical factors based on value choices. Weighting may include aggregation of the weighted results into a single score.

Finally, the interpretation phase consists in the assess of the findings obtained both at the inventory and the impact assessment phases. This assess allows the identification of the highest impacts or hotspots, their sources, and opportunities for improvement. In addition, the quantitative results obtained should be judiciously studied and validated in terms of consistency, wholeness, concordance, and conformity with the first expectations.

4. Goal and scope definition of underground hydrogen storages

The first LCA phase, definition of goal and scope, is common and general for both E-LCA and S-LCA, so the following sections include and encompass both aspects (environmental and social) but considering that environmental aspects refer to the E-LCA and social aspect to the S-LCA. The next project deliverables D6.3 (Report on the environmental impact of the underground H_2 storage) and D6.4 (Report into the social impact of the underground H_2 storage) will be separated and particularised for each LCA and will present a definitive and a more specific goal and scope definition as well as the inventory and final impact assessment results.

4.1. Goal

The main objective of these preliminary studies of the project is to evaluate the environmental and social performance of two underground hydrogen storage systems: salt cavern and porous media, for a better understanding and implementation, as well as those associated with the auxiliary systems that are needed to perform these types of storages, using specific data provided by Geostock.

The principal purpose is to quantify the environmental and social life cycle impacts of the underground hydrogen storage systems and to identify the processes with the largest impacts (hotspots), as well as to compare the different storage systems from a LCA perspective.

4.2. Audience

The study is intended for the partners of the Hystories project and other interested parties in the hydrogen sector, but not necessarily an expert in the field of LCA, and can be used to assist decision-makers decide on the implementation of energy storage methods considering the potential life cycle impacts (both environmental and social).

4.3. Functional Unit

The functional unit is the underground storage of 1 kg of H_2 produced through an electrolyser, stored for cycles of estimated time of 122 days (salt cavern) and 365 days (porous media) with a quality of 99.93%, a pressure of 70-180 bar for salt cavern or 60-130 bar for porous media and a temperature of 40-60 °C. The lifetime of both underground H_2 storages considered (salt cavern and porous media) is estimated to be 50 years. Both LCA studies use the same functional unit, however S-LCA often operates using information about the attributes or characteristics of processes and/or owning companies which are not relevant to express per unit of process output. In this case, such information is not summarized per functional unit during aggregation step in S-LCA and the results may be expressed quantitatively using life cycle attribute assessment in a way that renders the proportional weight of the unit process in the life cycle of the product under consideration (Benoît et al., 2010).

4.4. System boundaries

The system boundaries for both underground H_2 storages (salt cavern and porous media) include the stages of construction, use or operation (H_2 storage), and abandon or end-of-life of the storage (see Figure *2*). In both storages, the production of capital goods (buildings, machinery and equipment), energy, fuels, and materials consumed in all the stages was also considered.

The stages of H_2 production (water electrolysis, compression, etc…) and the H_2 final use were excluded in both storages because they are out of scope of the present study.

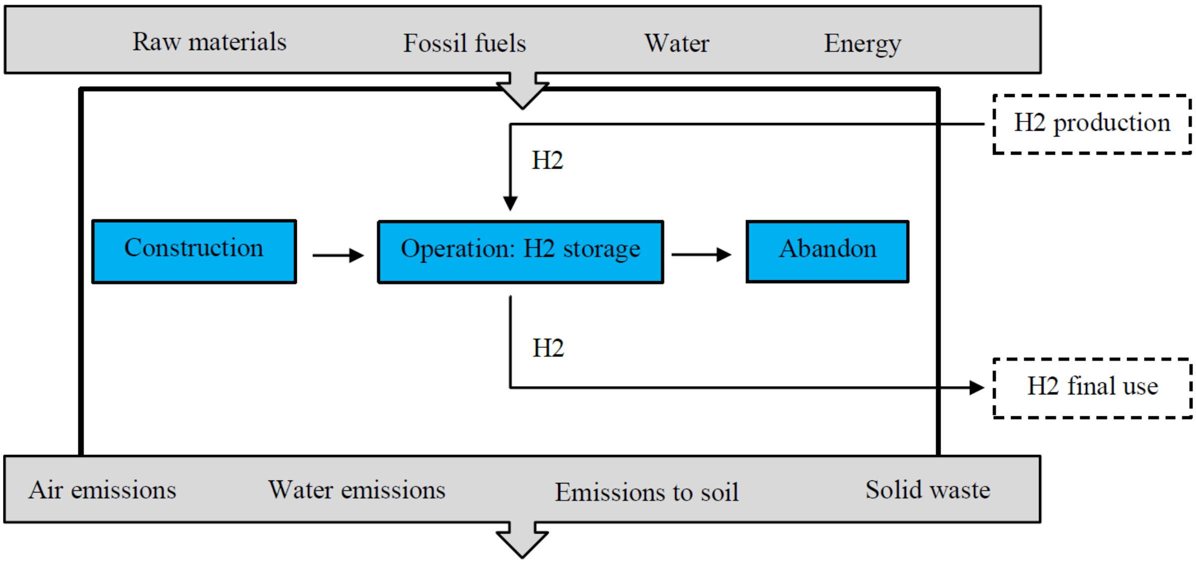

Figure 2: System boundaries in the life cycle of underground H2 storage systems. Solid boxes represent stages considered and dotted boxes represent stages excluded from assessment

The construction stage encompasses the processes of investigation, drilling&completion, leaching (only for salt cavern), surface facilities and buildings construction. It will require the consumption of industrial water, materials (such as cement, bentonite, barite, concrete, steel…) and chemicals, as well as seawater and nitrogen (for leaching phase) and the use of different machinery (drilling rigs, mobile crane, excavator, forklift) and freight transport (boats, trucks and semi-trailers) during this stage. The wastewater generated will be discharged into a wastewater treatment plant, the brine of the leaching phase will go to the sea (in our base case), and the solid waste generated will be recycled (65%) and the remaining (35%) will be landfilled according to the EU requirements by 2020 for construction and demolition waste (EU directive 2008/98/EC). The staff travel will be done by plane during this stage.

The use or operation consists of the H_2 storage during 50 years for both types of underground storages. This stage consumes electricity for the annual cycles and different consumables. Piping of the surface facilities will need to be renewed once over the 50-years lifetime due to the piping lifetime that is 30 years. Inspections of salt cavern volume evolution and casing part (for salt cavern and porous media, respectively) are compulsory during the operation, every 10 years for the former storage and for the latter, different wells are inspected every 2 years, but it is recommended to inspect the same well every 10 years. Salt caverns inspection consist of removing the piping and then introduction of a sonar logging tool or sampling to measure the volume at each angle of the cavern and lasts 20 days each cavern. The casing inspection lasts 10 days and only 4 wells are inspected each time. The staff travel will be done by car and plane during the operation stage.

The end-of-life or abandonment stage of the underground storages consists in the on-site inertization with nitrogen of approximately 50% of buried pipes, the removal of the remaining piping, surface facilities equipment, building and completion, and the well plugging and abandonment. For waste, it is assumed that non-hazardous solid wastes generated from buildings will be recycled (65%) and the remaining (35%) will be landfilled according to the EU directive (2008/98/EC), while the wastewater (sludge) will be discharged into a wastewater treatment plant. The staff travel will be by plane.

The D7.1-1 (Conceptual design of salt cavern and porous media underground storage site) and D7.2-1 (Life Cycle Cost Assessment of an underground storage site) include more detailed information about the development and operation of both underground storage technologies.

4.5. Software tools and data sources

Environmental and social LCA estimations will be performed, respectively, with GaBi and OpenLCA software. Inventory data (primary data) will be provided by Geostock, and complemented by GaBi (Kupfer et al., 2020) and PSILCA (Ciroth and Eisfeldt, 2016) database, secondary data for environmental and social assessment, respectively, as well as data from literature.

4.6. Selection of impact categories and indicators

4.6.1. Environmental impact categories and indicators

The impact assessment categories to be employed for the environmental assessment of underground H_2 systems were selected according to the latest development of the European

Commission on the recommended Environmental Footprint (EF) life cycle impact assessment methods (EC-JRC, 2018). Therefore, the environmental impact categories and the respective environmental indicator (or unit) selected for this analysis and frequently considered for this kind of case study (Osman et al., 2022; AlsShafi and Bicer, 2021) are the following:

- Climate change, expressed in kg CO_2 equivalents, and related to greenhouse gas emissions (carbon dioxide, methane, N_2O, chlorofluorocarbons (CFCs), halogens, etc.);

- Photochemical ozone formation, expressed in kg NMVOC equivalents, and caused by emissions of air pollutants NO_x and non-methane volatile organic compounds (NMVOCs);

- Acidification, expressed in mol H+ equivalents, and associated with emissions of acidifying substances (NH_3, NO_2 and SO_x);

- Eutrophication freshwater, expressed in kg P equivalents, is due to release of nutrients (phosphorus, phosphates) into soil and freshwater;

- Eutrophication marine, expressed in kg N equivalents, linked to release of nutrients (nitrogen, ammonium, NO_x) to water and soil;

- Resource minerals and metals, expressed in kg Sb equivalents, concerned to extraction of minerals resources (antimony, copper, aluminium, gold, etc.);

- Resource use fossil, expressed in MJ, reflecting the extraction of fossil fuels (crude oil, natural gas, coal, uranium, etc.).

4.6.2. Social impact categories and indicators

The preliminary social impact categories selected for S-LCA study to be evaluated under Hystories project concerning underground hydrogen storage in salt caverns and porous media are based on the specific goal of the project, stakeholder groups of interest for the project (workers and society) and literature review including Sustainable Development Goals and Guidelines for Social Life Cycle Assessment of Products and Organizations. For the “worker” stakeholder group, the following subcategories of social impact have been specified: working hours, fair salary, health and safety and discrimination. On the other hand, for “society” stakeholder category the social subcategory of social impact concerning contribution to economic development will be analyzed. The overview of the selected categories is presented in Table 2.

Table 2: Selected social impact subcategories related to different stakeholder groups

Stakeholder category	Subcategory
Worker	Fair salary
	Working hours
	Health and safety
	Equal opportunities/discrimination
Society	Contribution to economic development

This analysis will be supplemented by the information collected via interviews and questionnaires focusing on the general perception on the underground hydrogen storage covering categories such as technology development, public commitments to sustainability issues or community engagement, depending on the data availability.

Social risk of the proposed impact categories will be measured in medium risk (or opportunity) hours, which is the number of worker hours along the supply chain that are characterized by a certain social positive or negative risk (Mancini et al., 2018).

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