D5.3. A preliminary report into the environmental & socio-economic impacts of the project

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List of acronyms

CFCs	Chlorofluorocarbons
EF	Environmental Footprint
E-LCA	Environmental Life Cycle Assessment
eq.	equivalent
EU	European Union
FU	Functional unit
H_2	Hydrogen
H+	Hydrogen ion
HRS	Hydrogen Refueling Station
ISO	International Standard Organization
LCA	Life Cycle Assessment
N	Nitrogen
NMVOCs	Non-Methane Volatile Organic Compounds
P	Phosphorus
Sb	Antimony
S-LCA	Social Life Cycle Assessment
WP	Work Package

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1 Executive Summary

This document, *D5.3 A preliminary report into the environmental & socio-economic impacts of the project*, is a deliverable of *WP5 Impact Analysis and Business Models*, developed under the *Task 5.3* that aims to evaluate the environmental and socio-economic performance of the integrated hydrogen valley in the Northern Netherlands from a Life Cycle Assessment (LCA) perspective.

The objective of this report is to present the initial stages of the development of the environmental and social LCA to be performed in the framework of the HEAVENN project. These stages are fundamental for the following ones since they mark the findings to be obtained from the project and designate a clear road to realizing the final research report.

To this purpose, a brief introduction to the LCA methodology is given, the preliminary objective and scope of the study are described, and a section is included on the way in which the inventory information will be collected from the partners involved in Cluster I of the project.

This report will be updated and completed by *D5.4 An updated report into the environmental & socio-economic impacts of the project.*

2 Introduction

The HEAVENN project aims to address the use of green hydrogen across the entire value chain (production, distribution, storage and local end-use) into a fully integrated and functioning “hydrogen valley” located in the Northern Netherlands. Moreover, the project aims to maximise the integration of abundant renewable energy sources available in the region, such as solar (onshore) and wind (both onshore and offshore), using hydrogen as a storage medium to manage intermittent and constrained renewable inputs in the electricity grid, and as an energy vector for further integration of renewable inputs and decarbonisation across other energy sectors beyond electricity, namely industry, heat and transportation. The Work Package 5 (WP5) assesses the business model and environmental and social sustainability of the fully functioning green hydrogen chain in the Northern Netherlands for wide-scale commercial deployment of hydrogen across the entire regional energy system. Particularly, Task 5.2 focuses on environmental and socio-economic impact analysis of the integrated hydrogen valley in the Northern Netherlands to perform both the environmental and social Life Cycle Assessment (LCA). The results of both LCAs will be useful to reinforce, from an environmental and social perspective, the displaying of the replicability of hydrogen valley concept in Europe and beyond (Task 5.3).

The objective of this report is to provide the base for the development of the LCA to be conducted within the HEAVENN project framework. The main elements to be addressed in this deliverable are the preliminary definition of the goal and scope of the impact analysis of hydrogen valley in the Northern Netherlands and the procedure of the inventory data collection with the inputs from project stakeholders (responsible for each equipment or system to be assessed) based on the Cluster I example. This preliminary goal and scope definition includes aspects such as the identification of the functional unit and system boundaries, selection of impact categories and their respective indicators for both the Environmental-Life Cycle Assessment (E-LCA) and Social-Life Cycle Assessment (S-LCA) relevant to outline the systems to be analyzed and thus, together with the inventory data, to carry out the environmental and social performance analysis from an LCA perspective.

This report is structured in 7 chapters. The first one presents the introduction of this report. Chapter 2 describes the main characteristics of the hydrogen valley in the Northern Netherlands, Chapter 3 describes the LCA methodology applied, Chapter 4 defines the preliminary goal and scope of the hydrogen valley, including the impact categories and indicators selected for both E-LCA and S-LCA. The inventory data tables to be filled out by the partners involved in Cluster I appear in Chapter 5. Finally, Chapter 6 gives the main conclusions, and Chapter 7 lists the literature referred to in the report.

3 System general description: HEAVENN

The HEAVENN project emerges as a transformative initiative, spearheading the establishment of a fully integrated hydrogen valley in the Northern Netherlands. This undertaking encompasses the entire hydrogen value chain, from production to storage, transportation, and utilization, marking a significant step towards a sustainable energy future.

The project is structured around four distinct clusters, each tailored to address specific aspects of the hydrogen economy. The HEAVENN is composed of four clusters (see Figure 1), supported by and connected to various studies:

- Cluster I: Chemical Park Delfzijl. The activities and projects take place in the Eemshaven-Delfzijl region and comprise: a pipeline that supplies green H2, a so-called H2 hub that enables green H2 to be loaded onto trailers and transported to users in the region, and a hydrogen-powered barge that involves the deployment of a H2 fuel cell emergency power supply and includes H2 containers, a H2 refueling station (HRS) and a fuel cell.
- Cluster II: Storage and Built Environment. It encompasses a salt cavern for the underground H2 storage, trailers to transport H2 for heating in new-built and existing homes in Hoogeveen, and a data center that will be fitted with a power supply powered by a H2 fuel cell.
- Cluster III: Emmem Industry. It involves: an electrolyser to produce green H2 for the industrial park Getec Park.Emmen, and a H2 refueling station to supply green H2 to buses, and a gas turbine retrofitted to run on hydrogen.
- Cluster IV: Green Mobility. This cluster implicates: four H2 refueling stations for heavy transport and passenger vehicles, and other H2 transport applications (vehicle fleet: passenger vehicles, light and heavy-duty trucks, waste collection trucks, long-distance buses, 8-seater vans).

The equipment, infrastructures and systems of each cluster indicated in this report could undergo alterations and changes throughout the project (e.g. in 2024 it is expected that Djewels (in Cluster I) comes online and H2 will be produced from wind and solar energy), so at the project end they could be different and would be updated in the following report D5.4 *An updated report into the environmental & socio-economic impacts of the project*.

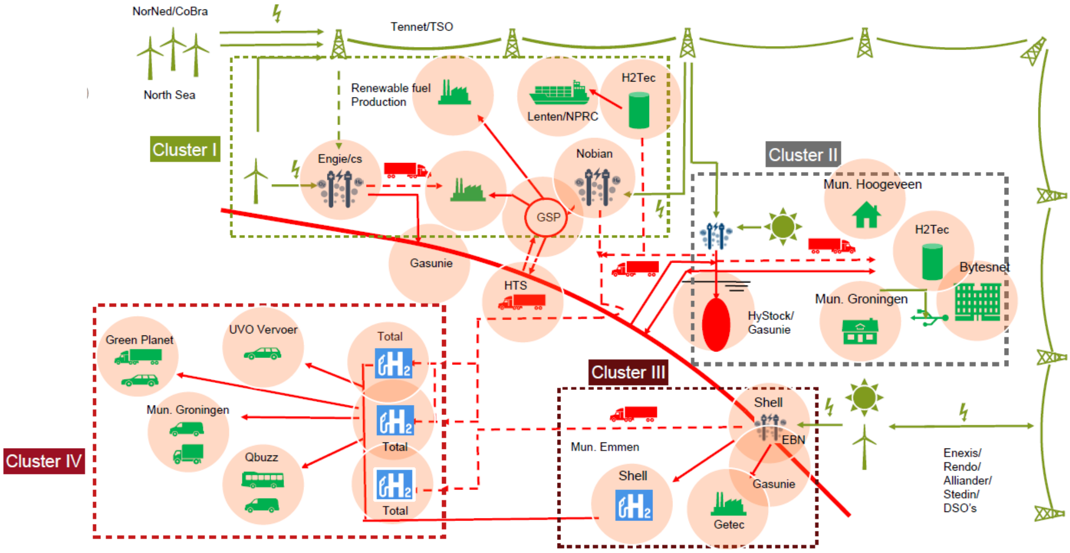

Figure 1: HEAVENN project structure

4 Methodology

Both E-LCA and S-LCA are based on the ISO 14040 framework (ISO, 2006a, 2006b). Therefore, although in certain aspects are different, both studies track the LCA methodology (based on environmental impacts) and are built in an analogous way and in accordance, since the initial phases for the analysis design and configuration are the same. The following section describes the LCA methodology.

4.1. Life Cycle Assessment

LCA is an ISO-framed methodology that originally compiles and assesses the environmental aspects and impacts associated to the life cycle of a product or service (ISO, 2006a, 2006b), i.e. from extraction and processing of raw materials, through production, distribution, use and maintenance up to end-of life (eventual reuse, recycling or disposal). LCA is generally considered an important life cycle thinking tool to carry out a quantitative (and qualitative in case of S-LCA) assessment of the environmental impacts of products, services, technologies or systems at large (object of the study), as it addresses both their entire life cycle as a broad range of environmental loads, thus becoming essential in supporting decision making where sustainability is a concern.
Figure 2 shows the four phases in which LCA methodology is structured (ISO, 2006): (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation. The four phases are interconnected, meaning that they use results from the other phases and feed each other (e.g. the interpretation interacts with the other three phases). Consequently, this framework allows for iterative and dynamic procedures within and between phases, which can lead to redefining, adjusting, or reconsidering any phase at any time during the analysis. Therefore, first the objective(s) of the work is defined and the initial configuration of the scope that defines the requirements of the subsequent work. Then, as more information becomes available during the inventory data collection phase and subsequent environmental and/or social impact assessment and interpretation, it will usually be necessary to refine and sometimes also revise the initial scope configuration.

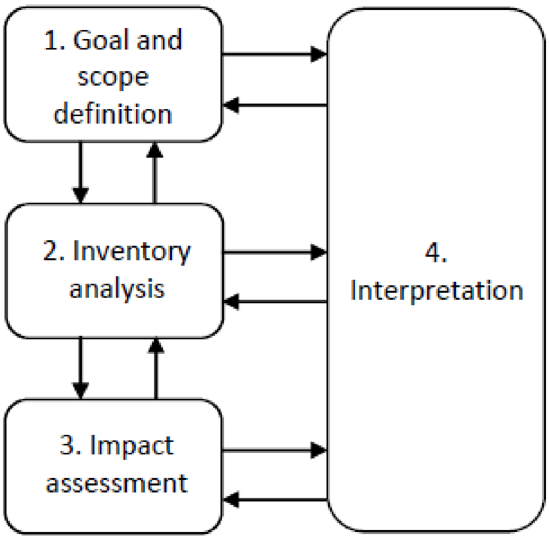

Figure 2: LCA structure

An LCA starts with the definition of the goal and scope. This first phase determines key features of the analysis including the depth and the breadth of an LCA, which can differ considerably depending on the overall goal. 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 life-cycle stages and processes to be included in the analysis;
- Definition of the functional unit (FU), 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 is the accounting phase and encompasses data collection for the processes previously identified within the system boundaries. These data comprise flows of inputs of material, energy and resources, and of outputs of waste, emissions to air, and co-products or monetary flows in case of S-LCA. The inventory analysis also includes calculation procedures so that the data collected for each process are summed up and related to the functional unit, whenever applicable. These inventory data are used to build the LCA modelling and then introduce or implement it into the LCA software.

The purpose of the impact assessment is to better understand the environmental and social significance of the inventory data by translating inputs and outputs flows into environmental and social impacts that are presented in different impact categories (e.g. climate change, acidification, eutrophication, resource use or so called "*social themes*" such as health and safety, working conditions, human rights or community impacts).

The interpretation is the last phase of the LCA procedure, in which the findings at the inventory and the impact assessment phases are summarized and discussed as a basis for the identification of the highest impacts or hotspots, their sources, opportunities for improvement, recommendations, conclusions and decision making in accordance with the goal and scope definition.

5 Goal and scope definition of the hydrogen valley in the Northern Netherlands

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 involve both aspects (environmental and social), considering that environmental aspects refer to the E-LCA and social aspect to the S-LCA. The next report foreseen under the HEAVENN project, D5.4 *An updated report into the environmental & socio-economic impacts of the project* will present a definitive and a more specific goal and scope definition for each impacts assessment, as well as the final inventory data and impact assessment results of the H2 valley in the Northern Netherlands.

5.1. Goal

The main objective of these preliminary studies of the HEAVENN project is to evaluate the environmental and social performance of the fully functioning green hydrogen chain in the Northern Netherlands, for a better understanding of these sustainability dimensions and identify improvement options for further replication of the project outcomes onto other hydrogen valleys of similar character.

The principal purpose is to quantify and assess the potential environmental and social life cycle impacts of the hydrogen valley in the Northern Netherlands and to identify the equipment, systems or areas with the largest impacts (hotspots).

5.2. Audience

These studies are intended for the use of HEAVENN project partners, actors involved in the development of hydrogen valleys and other interested parties in the hydrogen sector and can be used to assist decision-makers to decide on the implementation and replication of hydrogen valleys considering the potential life cycle impacts (both environmental and social).

5.3. Functional unit

The functional unit (FU) represents the production, supply, storage, or consumption of 1 kg of H2 under the specific conditions (purity, temperature, and pressure) applicable to each stage, depending on the equipment or system employed within the hydrogen value chain. Both LCA studies utilize the same FU; however, S-LCA frequently employs information about process attributes or characteristics and/or owning companies that are not pertinent to expressing results per unit of process output. In such cases, S-LCA does not aggregate this information per FU during the aggregation step, and the results may be expressed quantitatively using life cycle attribute assessment, allowing for the proportional weight of the unit process within the life cycle of the product under consideration to be represented (Benoît et al., 2010).Since S-LCA cannot always be conducted in a linear form, the FU might be defined in a descriptive manner, such as "*Providing hydrogen-based energy services to a community of 100,000 people for one year*," depending on the available inventory for conducting the social impact assessment."

5.4. System boundaries

The system boundaries for the hydrogen valley in the Northern Netherlands include all four Clusters. Considering the progress and advances of the project as a whole, for this first iteration, Cluster I has been selected as a base case, for further extrapolation of the methodology to conduct the full LCA of HEAVENN project. Therefore, the equipment and system considered for the preliminary LCA of Cluster I are: (i) the pipeline for the green H2 supply; (ii) the so-called H2 hub to load H2 into trailers and transport it to users in the region; and (iii) the H2 containers, (iv) the HRS and (v) fuel cell system for the H2-powered salt barge (see Figure 3).

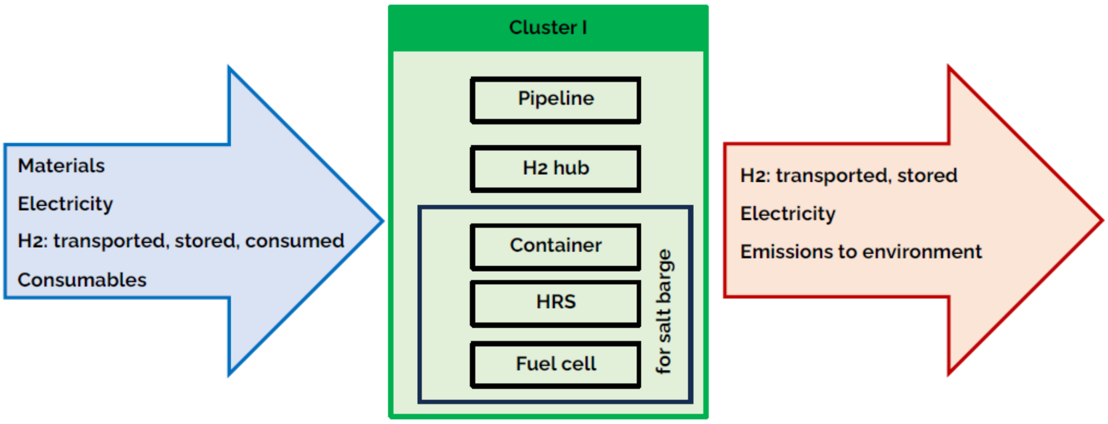

Figure 3: System boundaries of Cluster I

5.5. Software tools and data sources

E-LCA and S-LCA estimations will be performed, respectively, with LCA for Experts and openLCA software. Inventory data (primary data) will be provided by project partners, and complemented by LCA for Management (Kupfer *et al.*, 2020) and PSILCA (Loubert *et al.*, 2023) database, secondary data for environmental and social assessment, respectively, as well as data from literature.

5.6. Selection of impact categories and indicators

5.6.1. Environmental impact categories and indicators

The impact assessment categories to be used for the environmental assessment of the hydrogen valley in the Northern Netherlands 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 preliminary environmental impact categories and the respective environmental indicator unit selected are as follows:

- Climate change, expressed in kg CO_2 equivalents, and related to global warming potential of greenhouse gas emissions (carbon dioxide, methane, N_2O, chlorofluorocarbons (CFCs), halogens, etc.);
- Acidification, expressed in mol H+ equivalents, and associated with emissions accumulated exceedance of acidifying substances NH_3, NO_2 and SO_x);
- Eutrophication freshwater, expressed in kg P equivalents, is due to the fraction of nutrients (phosphorus, phosphates) reaching soil and freshwater;
- Eutrophication marine, expressed in kg N equivalents, linked to the fraction of nutrients (nitrogen, ammonium, NO_x) reaching water and soil;
- Photochemical ozone formation, expressed in kg NMVOC equivalents, related to tropospheric ozone concentration increase caused by emissions of air pollutants NO_x and non-methane volatile organic compounds (NMVOCs);
- Minerals and metals resource use, expressed in kg Sb equivalents, concerned to depletion of minerals abiotic resources (antimony, copper, aluminium, gold, etc.);
- Fossils resource use, expressed in MJ, reflecting the depletion of fossil fuels (crude oil, natural gas, coal, uranium, etc.).

5.6.2. Social impact categories and indicators

The initial social impact categories chosen for the S-LCA study to be assessed under the HEAVENN project regarding the hydrogen valley in the Northern Netherlands are grounded in the project's specific objectives, the stakeholder groups of interest for the project (workers, society, and local communities), and a literature review encompassing the Sustainable Development Goals and Guidelines for Social Life Cycle Assessment of Products and Organizations. For the "worker" stakeholder group, the following social impact subcategories have been delineated: working hours, fair salary, health and safety, and discrimination. Conversely, for the "society" stakeholder category, the social impact subcategory relating to contribution to economic development will be scrutinized. Additionally, for the "local community" stakeholder group, the social impact subcategory of possible "local employment" generated and community well-being will be assessed. This second subcategory encompasses factors such as air quality, noise pollution, access to local services, and overall quality of life for residents of the hydrogen valley region. The overview of the selected categories is presented in Table 1.

Table 1: 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
Local community	Local employment
	Community well-being

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).

6 Inventory of the hydrogen valley in the Northern Netherlands

To collect the data needed to build inventory based on the information provided by actors involved in various stages and Clusters of the HEAVENN project, a template Excel file was created, for its posterior adaptation to each of the subsequent Cluster structures and components, identifying each equipment, process or system involved. These templates are produced to facilitate the data collection process between the project partners and FHa, thus acting as main interface for data exchange, and also to group the documentation of inventory datasets and their consequent use in LCA modelling (e.g. for software implementation).

For the inventory data collection of each Cluster, a first contact was initiated with actors involved in the Cluster I, where the inventory data collection templates have been first introduced to the leader and partners attending the meeting with the purpose to provide a general overview and to address any potential questions. Partners involved in that activity were then asked to fill the template as completely as possible, that would allow feedback collection by FHa and be a subject for subsequent meetings required for clarifications and potential re-sending of the template for the data collection. This strategy aims to enhance the communication among the involved parties and aid in the mitigation of some project risks that might materialize over the project duration such as delays due to e.g. unclear instructions or data availability.

Following tables (Table 2 to 6) show the information of interest requested from the parties involved in Cluster I. Partners should complete the quantity associated to the type of information requested and indicated in the first column and the corresponding unit, as well as to provide any comments related with the information supplied that might be useful for the data interpretation by FHa. Table 2 corresponds to the pipeline for green H2 distribution, Table 3 to the H2 hub, Table 4 to the containers of H2 for the H2-powered salt barge, Table 5 to the HRS for the salt barge and Table 6 to the fuel cell system for the salt barge. Table 7 has been introduced to accommodate possible scenarios of energy supply for H2 production that might be necessary to take into account in the impact studies.

Over the course of the project, all four Clusters of the HEAVENN project will be contacted and asked to provide their respective inventory data.

Table 2: Inventory table for H2 pipeline of Cluster I

	Amount	Unit	Comments
Material* (indicate type)			
Material* (indicate type)			
Insert line			
H2 transported (expected)			
H2 transported purity			
H2 transported temperature			
H2 supplied pressure			
Lifetime (expected)			

* Indicate the main materials of the equipment, taking into account critical raw materials (platinum, iridium, nickel…).

Table 3: Inventory table for H2 hub of Cluster I

	Amount	Unit	Comments
Material* (indicate type)			
Material* (indicate type)			
Insert line			
H2 capacity			
Electricity consumption			
Inlet pressure temperature			
Outlet pressure			
Lifetime (expected)			

* Indicate the main materials of the equipment, taking into account critical raw materials (platinum, iridium, nickel…).

Table 4: Inventory table for H2 containers of salt barge of Cluster I

	Amount	Unit	Comments
Material* (indicate type)			
Material* (indicate type)			
Insert line			
H2 capacity			
H2 Pressure			
Lifetime (expected)			

* Indicate the main materials of the equipment, taking into account critical raw materials (platinum, iridium, nickel…).

Table 5: Inventory table for HRS of salt barge of Cluster I

	Amount	Unit	Comments
Material* (indicate type)			
Material* (indicate type)			
Insert line			
Electricity consumption			
Refueling capacity (expected)			
Lifetime (expected)			

* Indicate the main materials of the equipment, taking into account critical raw materials (platinum, iridium, nickel…).

Table 6: Inventory table for fuel cell system for salt barge of Cluster I

	Amount	Unit	Comments
Material* (indicate type)			
Material* (indicate type)			
Insert line			
Electricity consumption			
Power to the grid			
Consumables (gases, chemicals, …)			
Insert line			
H2 consumption			
H2 pressure			
H2 temperature			
Frequency of maintenance			
Efficiency			
Operating hours (expected)			
Lifetime (expected)			

* Indicate the main materials of the equipment, taking into account critical raw materials (platinum, iridium, nickel…).

*Table 7: Inventory table of energy origin scenarios for H2 production of Cluster I**

	Share (Scenario 1)	Share (Scenario 2)	Share (Scenario i)
PV			
Wind energy			
Dutch grid			
Other origin			

* Due to it is expected that Djewels comes online in 2024 and H2 will be produced from wind and solar energy.

The life cycle inventory of the LCA will form the basis for both LCA studies (environmental and social), however for the S-LCA study further data such as worker hours and specific social data will be required. In the Table 8, a preliminary list of social indicators, with associated units and references has been presented. These indicators depend on the final structure of the HEAVENN project, equipment and resources implemented, therefore the list presented in this deliverable might be a subject for adjustment based on the information available, if necessary. Given that S-LCA results are country dependent, the respective actors may be additionally asked about the information related with the country of origin/production of the component/service or industrial process under consideration.

Table 8: Social data inventory table with selected social indicators

Social indicator	Unit	Amount	Comments
Labor time estimation	h		
Manpower	person		
Manpower Cost	Euro		
Contribution of the sector to economic development	% of GDP		
Cases of violations of laws and employment regulations	Cases per x employees in n years		
Gender wage gap	% difference male and female wages in reference year		
International migrant workers in the sector	% of total employment in the sector in reference year		
Implementation of sufficient safety measures	OSHA cases per x employees over n years		
Rate of fatal accidents at workplace	no./yr per x employees		

Social indicator	Unit	Amount	Comments
Rate of non-fatal accidents at workplace	no./yr per x employees		
Sector monthly average wage	Euro		
Weekly hours of work per employee	h		
Men employed in the sector	Ratio of women employed in the sector to total employment, %		
Women employed in the sector	Ratio of women employed in the sector to total employment, %		
Increase of jobs created	% of increase in the sector employment with relation to year x		
Country of origin	-		

7 Conclusions

This report presents the initial phases of the development of the E-LCA and S-LCA to be carried out in the framework of the HEAVENN project. To this end, a brief introduction to the LCA methodology has been provided, as well as the preliminary definition of goal and scope of the hydrogen valley in the Northern Netherlands. Additionally, a section covering the approach on how inventory data information will be gathered, based on the example of partners involved in Cluster I (that will be adapted to the four project clusters), has been included. These LCA phases are decisive for the following ones as they mark the results to be obtained from the project.

This document will be updated and completed within the report *D5.4 An updated report into the environmental & socio-economic impacts of the project*. Both reports serve a basis to explore the environmental and social aspects and implications of the burgeoning, growing and promising field of green hydrogen valleys through the life cycle-based perspective to support the development and replication of sustainable and competitive green hydrogen valleys.

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