LIFE ELEKTRA

D4.1

ELEKTRA CIRCULAR IMPACT ANALYSIS METHODOLOGY

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ABBREVIATIONS AND ACRONYMS

LCA	Life-Cycle Analysis
S-LCA	Social Life-Cycle Analysis
LCC	Life-Cycle Cost
ZLD	Zero Liquid Discharge
DWTP	Drinking Water Treatment Plant(s)
WHO	World Health Organisation
LCSA	Life-Cycle Sustainability Analysis
EDR	Reverse Electrodialysis Plant
CF	Characterisation factor(s)
WWTP	Wastewater Treatment Plant(s)
NGO	Non-Governmental Organisation
EMRHS	Energy Management and Renewable Hybridization System
CAPEX	Capital Expenditures
OPEX	Operation Expenditures

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Executive summary

Project **LIFE ELEKTRA** aims to implement a groundwater denitrification prototype whose successful application can be of great relevance given the pressing environmental need to limit the amount of nitrates in drinking water. However, the successful development and implementation of the prototype proposed in the project involves designing and implementing an industrial water treatment process that is intended to be sustainable and efficient for both environment and society, as well as achievable in terms of costs. Furthermore, it is important to highlight the strong circular nature of the process being developed, since not only energy is consumed, it is also generated through the generation of renewable Hydrogen. Likewise, the valorisation of different by-products and the recirculation of already treated water flows are carried out.

For all this, a circular impact analysis methodology is necessary that addresses the quantification of impact and analysis of ways to optimize it transversally to the different use cases of the designed plant. The LCA analysis to be carried out is described, which in turn is complemented by the consideration of the social approach (S-LCA) and costs (LCC). These environmental impact analysis procedures share the same basis according to which an object of study and scope is defined, an inventory is developed, and an impact analysis is carried out on said inventory. The application of these procedures must be carefully planned given the enormous amount of data they usually require, since the quantification of impacts is a complex process that involves a high level of detail. As a counterpart, an unequivocal view of the effective impact of the physical object of analysis on the environment and at the socioeconomic level is obtained. In the case of **LIFE ELEKTRA**, it is important to note that an important task of adapting the LCA methodology has been carried out to be applied to a novel process in the development phase.

The document ends by describing the other two tools that will be developed and launched in the pilot. The Energy Management and Renewable Hybridization System fulfils the double function of monitoring and controlling the process from a field point of view, with functions similar to those that a SCADA or MES system can carry out. However, its design, development and deployment must be carried out according to the particularities of the **LIFE ELEKTRA** pilot, which consists of an iterative start-up phase and a validation phase. On the other hand, the Digital Twin of the plant seeks precisely to fill the gap left by the other two tools, examining those use cases not foreseen in the physical implementation, and also seeking to analyse scenarios in which the plant can be replicated.

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1. Introduction

Ground water contamination arises as a relevant problem for various European Union Members States. Therefore, water bodies are affected by nitrates as a main source of pollution due to its excessive use through fertilizers in agriculture or improper water disposal, among others. High nitrate levels can lead to eutrophication and, most importantly, nitrates in drinking water pose health risks to humans. For this reason, the denitrification process, which removes these nitrates from the target water stream using different techniques, has a fundamental role to play in ensuring safe and reliable drinking water. The project aims to scale up an innovative electrochemical denitrification process to different application cases considering the cleanest, most sustainable, and efficient way to do it.

A differentiating aspect of the project is the elimination of nitrates from the water stream through their transformation into different by-products, without the need to generate streams with high nitrate concentrations and, thus, with the possibility of moving towards a Zero Liquid Discharge (ZLD) scenario. However, the process of scaling up the plant involves a series of requirements to fulfil and sub-processes that are key to adjusting the conditions of the water stream to the needs of the electrochemical denitrification stage. Moreover, the pilot plant demands electricity as its main energy source, which supports the coupling of renewable energy generation systems. The management of the plant's energy, both generated and consumed, as well as the effective use of the hydrogen stream generated are fundamental aspects to achieve the project's objectives.

For this purpose, it is essential to perform a holistic circular analysis approach structured in four main pillars corresponding to the most important dimensions to be considered in the development of the plant to different scenarios: environmental sustainability, energy consumption, social impact, and economic feasibility. As a result, the ELEKTRA Analysis Methodology for the denitrification process is raised aligned with the requisites of the project and key actuations such as the implementation of different prototypes, with the objective of providing a complete, reliable crosscutting analysis of the current and future impact of the plant in the related terms.

1.1. Purpose of the Deliverable (D4.1. ELEKTRA Circular Impact Analysis)

This deliverable aims to describe in detail the Circular Impact Analysis Method to be carried out in the **LIFE ELEKTRA** project. This description includes the context of development and application (and subsequent correlation with the rest of actions), the requisites, a detailed description, and the scenarios considered for the implementation.

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2. General context of the project

LIFE ELEKTRA consists of an innovative process of electrochemical denitrification of wastewater with a high concentration of nitrates (NO_3^{-2}) as an alternative to the current situation where this flow is disposed for treatment by wastewater treatment plants (WWTPs). The project main objective is to **demonstrate on an industrial scale the electrochemical denitrification technology** designed to eliminate nitrate content of a reject water stream from Drinking Water Treatment Plants (DWTPs). Complex reactions take place on the electrochemical denitrification stage, which breaks down the cited pollutant into by-products, including nitrogen as an inert gas and hydrogen as a high value-added gas. This method eliminates the problem instead of displacing it to other treatment stages as is the case of nitrate separation techniques that keep these chemical species unaltered.

According to the World Health Organization (WHO), the maximum allowable level of nitrates in **drinking water is 50 mg/l**. This value is also included in the Drinking Water Directive and other national regulations. This restriction is justified by the fact that the intake of considerable amounts of these substances can pose a **health risk**, as they have been linked to pathologies such as **methemoglobinemia, cancer or endocrine system disorders**. From an environmental point of view, nitrates are a chemical species that has the power to **eutrophicate water bodies**. Eutrophication is a biological process by which, given the high concentration of nutrients in the water (nitrates or other species), organisms that feed on them begin to proliferate massively, **unbalancing the ecosystem**. These populations prevent oxygen and sunlight from penetrating the water layers, causing severe damage to the aquatic ecosystem, and generating the massive death of individuals.

Therefore, the aim is to provide a solution to the need to reduce the concentration of nitrates to **below 50 ppm** (mg/l), the limit indicated by Directive (EU) 2020/2184 for groundwater while reducing, to a certain extent, the overexploitation of aquifers by decreasing the extraction flow since part of the regenerated water would be reused. A project of this magnitude requires an analysis to quantify and evaluate the environmental, social, and economic impact. It is important to conduct an environmental and socioeconomic study to validate the sustainability of the proposal and identify possible critical points for improvement. These will be monitored through the Life Cycle Sustainability Analysis (LCSA). This will make it possible to monitor and evaluate the needs presented by the project in the three axes proposed.

Nevertheless, energy plays a highly significant role when analysing all the three previously referenced axes, since energy efficiency is a key determinant of the project's overall sustainability. Energy consumed in each stage of the process has direct implications on its environmental, economic, and social feasibility. Therefore, an extensive work on energy efficiency analysis and optimization of the pilot plant is required, resulting in identifying the need to design and set up an Energy Management and Renewable Hybridization System (EMRHS), which involves managing and optimizing the operation of the plant combining renewable energy generation and process operational efficiency. This approach not only reduces process' carbon footprint but also contribute to its economic feasibility by lowering operational costs and even has social implications related to potential impacts of energy use on the local context.

Consequently, the importance of the WP4 lies in its cross-cutting nature through an impact analysis methodology that evaluates all actions, as shown in the following figure:

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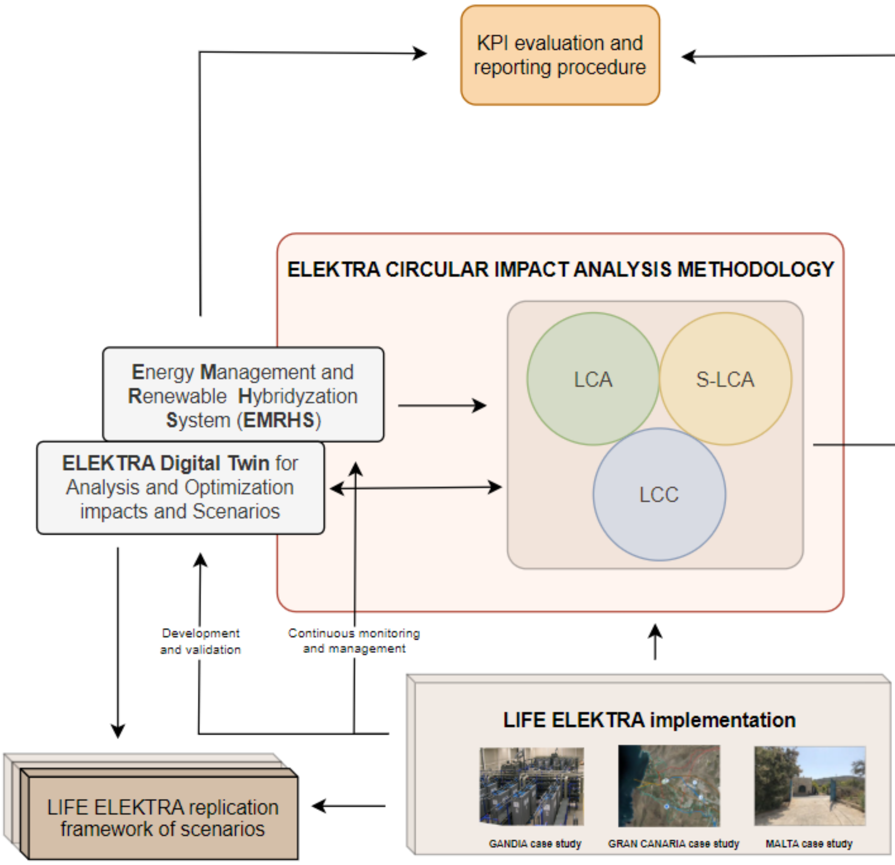

Figure 1. Scope of WP4 regarding the requirements of the project. Source: ITE

As can be seen, the circular analysis methodology is not limited to the triple analysis LCA-LCC-SLCA, but these three approaches are the basis for a particular analysis of each application case, as will be described below.

On the other hand, the scaling up of the process and implementation of the pilots is not exempt from foreseeable changes, and therefore requires monitoring that also provides part of the information necessary for the project KPIs. To this end, the EMRHS must be designed in such a way as to gather and pre-tract as much information as possible during the testing and start-up phase of the prototypes, with a focus on continuous operation and analysis.

The Digital Twin complements the use of the two previous tools by providing a data-driven analysis that projects scenarios for predictive and prospective analyses that address the scalability and replicability of the plant to other usage scenarios. These concepts are developed in greater detail in each of the sections of the deliverable, a summary of the use of each of the tools is shown in the following table:

Table 1. Summary of analysis tools and their use in the context of Circular Impact Analysis of LIFE ELEKTRA. Source: ITE

	ELEKTRA LIFE TIMELINE	End Of Project	Simulations
MAIN TOOL	Energy Management and Renewable Hybridization System (**EMRHS**)	**Environmental analysis approach:** **LCA +** **S-LCA +** **LCC**	**ELEKTRA Digital Twin** for Analysis and optimization impact of scenarios
FUNCTIONS	Main source of information Energy management system Continuous monitorization of the pilot plant	Provides information about the sustainability of the process Integrates cost and social impact analysis	Focused on scalability and replicability Also used to help analyzing results when no sufficient data is available
KIND OF ANALYSIS	Dynamic analysis Recurrent in time Iterative	Static analysis Main results obtained when pilot plant is implemented (Analysis based on project results) Based on defined scenarios	Predictive Prospective Based on many different possible scenarios

Despite indicating a static analysis obtained as a result of the implementation of the pilot plant, the triple LCA analysis must be carried out throughout the project, including partial evaluations of it. However, the final result corresponds to the final life cycle evaluation with the pilots already operational and consolidated, which is the reason why a static analysis has been considered to provide a snapshot with all the available information of the process. In any case, it can be seen how each of the tools complements the rest, as they provide complementary analysis approach of the same process. The fact that all the tools are included under the umbrella of the same methodology is due, precisely, to the need to unify criteria in a coherent, single approach. This aspect is described in more detail in *process data generation and collection protocol point.*

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3. Environmental and socio-economic monitoring and assessment

As mentioned above, the project aims to provide a solution to the environmental and social problems caused by the discharge of water with a high concentration of nitrates into bodies of water. Hence, the objective of the process is the denitrification of the reject water, whether it comes from well water that is already contaminated, reject water from a drinking water treatment process or from a desalination plant.

With the monitoring and evaluation of both scenarios it is intended to obtain the **Life Cycle Sustainability Analysis (LCSA)** of the new process of recovery of water contaminated by nitrates, following the LCA methodology. It is important to carry out an environmental and socioeconomic study to validate the sustainability of the proposal and **identify possible critical points for improvement**. At the same time, it is intended to identify opportunities for improving environmental and socioeconomic performance, to adjust the proposed process to **reduce** any **undesirable effects**.

3.1. Scenarios for Life Cycle Analysis

As a common point to the three already described approaches, analysis scenarios for impact assessment should be conveniently defined according to the methodological references cited below. These scenarios correspond to the selected cases of analysis comprised in the Life Cycle approaches according to the referenced methodology. The Life Cycle approaches of **LIFE ELEKTRA** will consider two main scenarios:

Current scenario, in which nitrates are not transformed from reject water generated by an EDR (electrodialysis reversal) plant, a desalination plant or well water for human consumption.

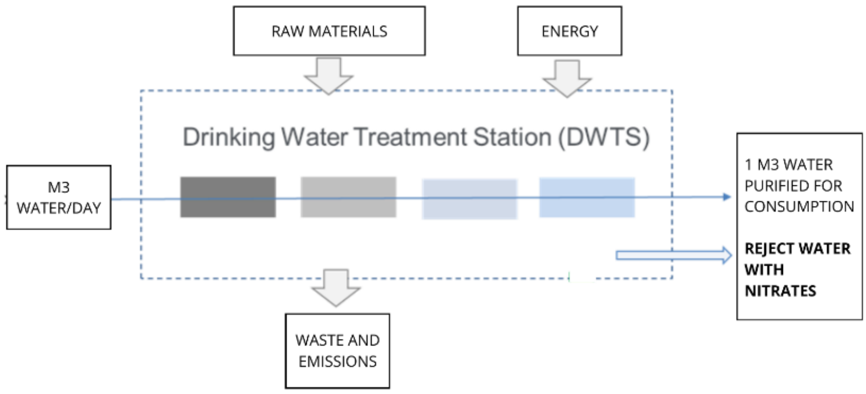

Figure 2. General diagram of the current scenario. Source: ITE

New scenario, in which the electrochemical denitrification process is implemented to remove nitrates from the water in the form of nitrogen to the atmosphere and hydrogen gas is generated for energy storage in fuel cells.

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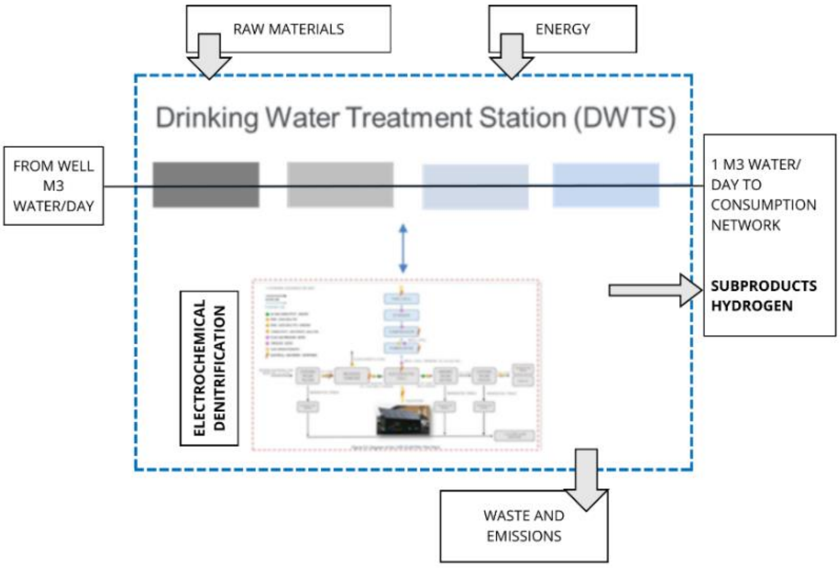

Figure 3. General diagram of the new scenario: Source: ITE

It has been necessary to identify and define the two scenarios since the life cycle sustainability analysis of **LIFE ELEKTRA** aims to assess the impact of the project on society, the environment and the economy. This will only be possible if a comparison is made between the situation with and without the treatment plant. It seems clear that, in both scenarios, the functional unit of reference will be the water leaving the plant which, having already been made potable, will be injected into the network for consumption. The difference lies in the fact that, in the first scenario, it is foreseeable that more input water will be consumed to inject the same amount of water into the consumption network as there is part of the input flow that is discarded as reject water with a high concentration of nitrates. On the contrary, in the new scenario, as the plant using the **LIFE ELEKTRA** pilot will be able to recirculate part of the reject water back to its header, it will probably be necessary to extract less flow from the well to inject the same amount of drinking water into the consumption network.

Moreover, two plant sizes are analysed as implementation varies depending on considered use case. The greater plant, with a reference value of nominal capacity of 4 m^3/day will be implemented in Gandía, while the smaller version of the plant, with a capacity of 2 m^3/day will be implemented in Gran Canaria and Malta. In this regard, defining use cases involves designing a general evaluation framework that must be adapted to each of the **LIFE ELEKTRA** pilot implementations, as each of them has its particularities, including the previously cited scale of the denitrification plant and the composition and quantity of treated water. The most important use case is the **Ull de Bou plant in Gandía**, which has the following characteristics:

- Ull de Bou produces an average of 16.000 m^3/day of treated water (32.000 combined with its twin plant of Falconera). This amount varies along the year due to the rise of population in summer.
- A 10 % of this production is considered as estimated reject fraction of the plant.
- Water is extracted from San Juan Well, Beach IV-I Well and Beach IV-II Well, whose nitrates compositions along last years can be represented as follows:

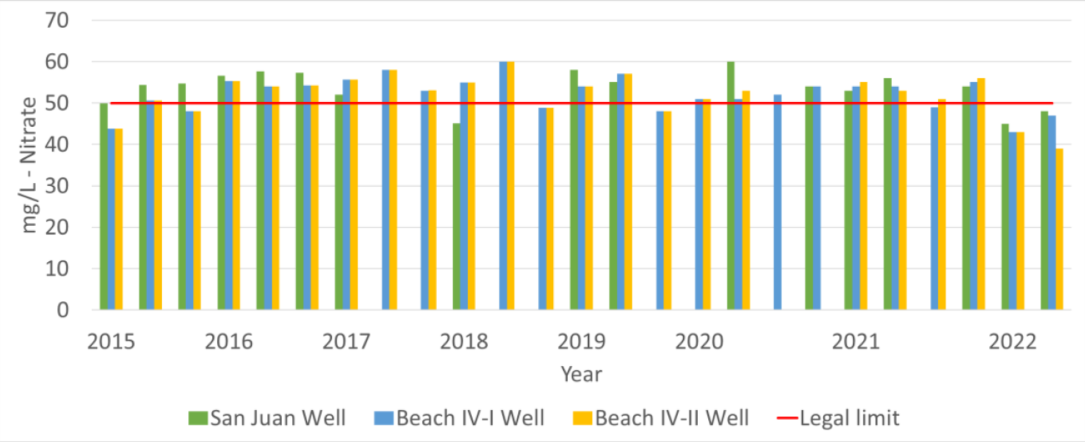

Figure 4. Nitrate concentration evolution in different wells in Gandia. Source: AVSA

- Operational limit of Ull de Bou is 25 mg/l due to a private contract of supply, half of the legal limit (50 mg/l).
- A nominal capacity of 4 m^3/day is intended to be reached in Gandia, corresponding to the "new ELEKTRA plant" obtained from scaling up the original ELEKTRA plant (which has a nominal capacity of 2 m^3/day in cationic resin filtration). This capacity shall be confirmed through the implementation process.

The second use case is the water treatment plant in **La Aldea de San Nicolás**, Gran Canaria. This municipality is characterized by obtaining drinking water by combining the desalination of seawater with the purification of an aquifer. This use case presents the following characteristics:

- The groundwater to be treated has a high uptake of catchments mainly due to agricultural activity in the area.
- An average value of 247 mg/L of nitrates to be treated is estimated with a rising trend. This deviation from the threshold has led to control and even restrict water consumption in some water supplies of the zone. Desalinization arises as the main technology to supply drinking water, entailing a higher energy consumption.
- Since the smaller version of the plant will be implemented, a nominal capacity of 2 m^3/day is considered, which corresponds to the nominal capacity of the first step of the plant (cationic resin filtration). Nevertheless, the global capacity of the plant will be studied in detail along with adaptations and improvements achieved during design phase.

The third use case corresponds to **Bingemma pumping station**, located in **Mgarr, Malta**.

- Malta water system presents approximately a 40 % of rate of groundwater use. A higher salinity and nitrate (from farm waste) intrusion has been identified in this kind of water, resulting in a plan to increase desalinization systems.
- Bingemma station provides drinkable water and usually has a high nitrate content. Improving nitrate elimination is a priority given Malta's high dependence on water supply.
- As for Gran Canaria use case, the smaller version of the plant will be implemented in this location, same considerations apply.

To conclude, a summary of reference of water physicochemical composition for every use case:

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Table 2. Water conditions in every use case.

Use Case	Water flow	NO3 (mg/L)	pH CE	(µS/cm)
Gandia Ull de Bou	Corresponding to reject to be treated	420 (~45-60)[1]	7	4000
Groundwater from La Aldea well, Gran Canaria	Corresponding to ground water	253	7,7	1617
Groundwater from Bingemma, Mgarr, Malta	Corresponding to ground water	143	7,3	5987

An important clarification should be made regarding the above table, as the Gandia water conditions correspond to the conditions of the reject flow generated by the EDR plant, while the other two samples correspond to average ground water characteristics. In fact, it can be stated that groundwater extracted in Gandia present a lower nitrate level than La Aldea and Bingemma use cases. It should also be noted that the values obtained for the latter two cases are reflected as averages of the information provided by each of the partners.

In conclusion, each case of application must treat a water flow with specific characteristics that will certainly imply adjusting the application of the **LIFE ELEKTRA** pilot to the requirements of both that water composition and its final consumption. In fact, as an example of this, it can be anticipated that, in cases where a low concentration of nitrates is available, the work of the reverse osmosis stage will foreseeably be greater until the water composition requirements for denitrification are reached. However, it is important to analyse each of the application cases considering Circular Impact Analysis Methodology to obtain relevant and comparable conclusions in the context of each application. A brief description of the three basic methodologies is given below.

3.2. Brief introduction of LCA, S-LCA and LCC approaches

Life Cycle Environmental Assessment (LCA): The methodology used to calculate and compare the environmental impacts of the two scenarios will be the life cycle analysis (LCA) based on the international standards ISO 14040 – 14044 related to environmental management and life cycle assessment (*ISO 14040: Principles and framework; ISO 14042: Life cycle impact assessment; ISO 14043: Life cycle interpretation; ISO 14044: Requirements and guidelines*). Different scientific methodologies are available to carry out life cycle impact assessment. These calculation methodologies are embedded in software tools available for this purpose. **SimaPro** is selected as the main environmental analysis tool and specifically using **ReCiPe** calculation methodology. The life cycle assessment will consider the environmental impacts in terms of materials and energy fluxes at process level as well as include the entire life cycle of the pilot plant equipment, from manufacturing, transport, and installation to the final dismantling. The current scenario will be compared with the new circular one to calculate the environmental impact of the project. In addition, environmental hotspots will be identified, and proposals will be made to optimize the environmental performance.

[1] As already described, this range of values correspond to an average estimation of nitrate composition of Gandia wells, rather than reject flow obtained from the plant.

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Social Life Cycle Assessment (S-LCA): The methodology used to assess the impact of the proposed solution on society is based on the S-LCA concept considering an entire life cycle approach and the particularities of each demonstration area. Specifically, it will take as a reference the draft international standard ISO/DIS 14075, prepared by Technical Committee ISO/TC 207, Environmental Management, Subcommittee SC 5, Life Cycle Assessment, which is based on the international standards ISO 14040 – 14044. Moreover, social Hotspots Data Base is an interesting procedure that will be used in the social analysis, which provides an extensive list of indicators grouped into 5 categories: labour rights, health and safety, human rights, governance, and community infrastructure, that will be evaluated at a global and local level.

As in the environmental study, the impact indicators obtained for both scenarios (before and after the improvement) will be compared to analyse negative and positive consequences on people's well-being due to the project's activities.

Life Cycle Cost Assessment (LCC): The LCC methodology will be used to evaluate all the economic costs associated with the complete life cycle of the pilot prototype and its escalation to industrial level, including direct costs and environmental externalities.

The procedure used for the economic evaluation will be analogous to that used for the environmental evaluation in terms of scope (functional unit, system boundaries, scenario comparison, etc.), and it will be based on the international standards ISO 14040 – 14044, since no specific standard have been developed for life cycle cost study. The costs of environmental externalities will be calculated by applying monetization factors to the identified impacts.

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4. LCA Methodology

According to the methodology proposed by the ISO 14040 international standard that establishes the *Life Cycle Assessment. Principles and framework* [1], an LCA procedure can be divided into 4 phases: **objectives and scope of the study**, **inventory analysis, impact analysis and interpretation**. As shown in the figure below, these four phases are not necessarily sequential, but are stages that feed into each other, allowing the successive stages to be expanded in detail.

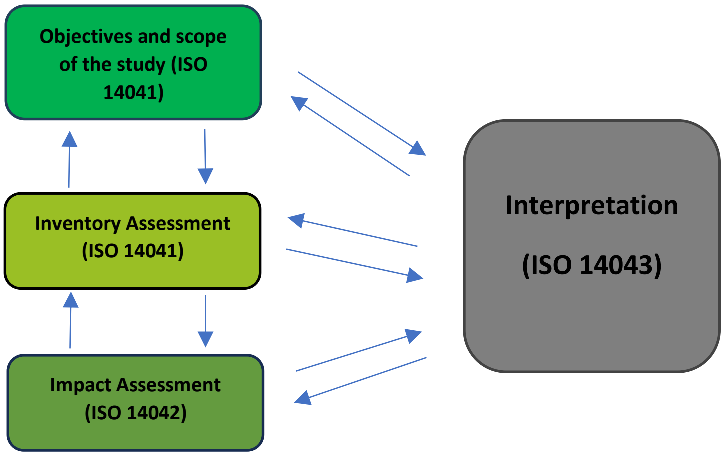

Figure 5: phases of an LCA according to ISO 14040. Source: ITE from ISO 14040

4.1. Objectives and scope of the LCA

According to ISO 14040, *the goal of an LCA states the intended application, the reasons for carrying out the study and the intended audience*, the scope of the study should be sufficiently well defined to ensure that the breadth, depth, and detail of the study are compatible and sufficient to address the stated goal.

In this section, it will be explained how to determine the objectives and scope of the environmental life cycle analysis, therefore it is necessary to first introduce the main concepts that need to be defined in this stage of the study:

- The **functional unit** serves as a basis for comparison between systems and is used to quantify the functional inputs and outputs of a production or service system. The calculation of the results obtained will be extrapolated on this unit.
- **System boundary** is understood as the delimitation of the system under study. In other words, it consists of delimiting the stages of the process for which environmental impacts are analysed. The system boundary defines the **unit processes** to be included in the system.
- **Scope** is understood as a complementary concept to the system boundary and is defined according to the final aim of the study. The scope determines the breadth of the analysis framework and the stages of the value chain that will be considered in the environmental assessment (Figure 6).
- **Inputs** and **outputs** are referred to the energy and material balance of the system, according to the environmental relevant information.

In this phase, the subject of study will be defined and the reasons that lead to the application of this life cycle analysis will be included. The main objective and the specific objectives of the analysis applied to the **LIFE ELEKTRA** project will be determined and the functional unit will be established.

A life cycle analysis of a process such as the one that supports the **LIFE ELEKTRA** project can be very extensive, therefore it is necessary to establish boundaries and scopes. The definition of the scope of the LCA must be able to answer the question of how far the impact analysis will go (Figure 6).

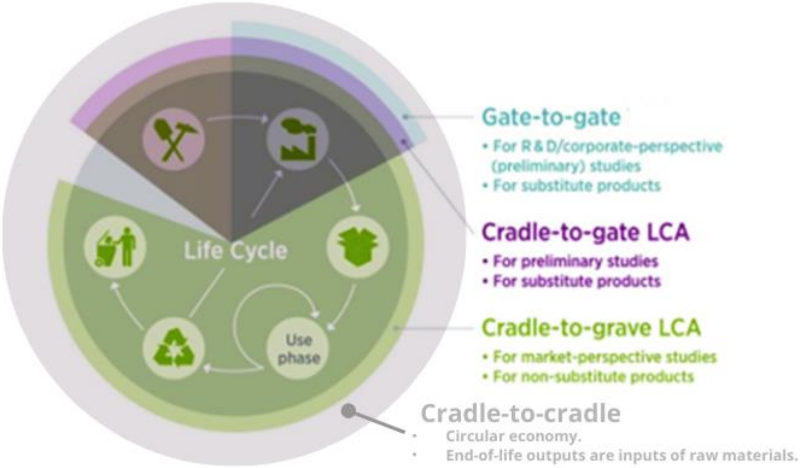

Figure 6: Scope of LCA in the product life cycle: Source: Cremonese et al.,2020 [2]

Although the purpose of this document is to establish the methodology to be followed rather than to describe the steps themselves, it is interesting to at least define the scope of the LCA to facilitate understanding of the following sections. It is considered that it makes more sense to initially establish what will be evaluated before explaining how it will be evaluated. The study will be carried out considering two boundaries of the system under study, each of them with its objectives and scopes:

Boundary 1: Study of the environmental impact of the denitrification process of the DWTP reject water for recirculation to plant headworks. The unit process included corresponds with the different stages of the new wastewater treatment proposed in **LIFE ELEKTRA**.

Objective: The new treatment process (pilot plant) will be analysed separately, to have perfectly identified and detailed both positive and negative impacts related to its implementation.

Functional unit: It is determined that the functional unit for this study boundary will be 1 m^3 of recirculated water because the system to be studied starts with the entry of the reject water with high nitrate concentration and ends with the outlet of the denitrified water which is re-injected into the drinking water treatment plant.

Scope: from **gate to gate** (Figure 6) this will be from the time the reject water enters the process (flow rate to be determined) until the clean water exits and is recirculated to the plant headworks.

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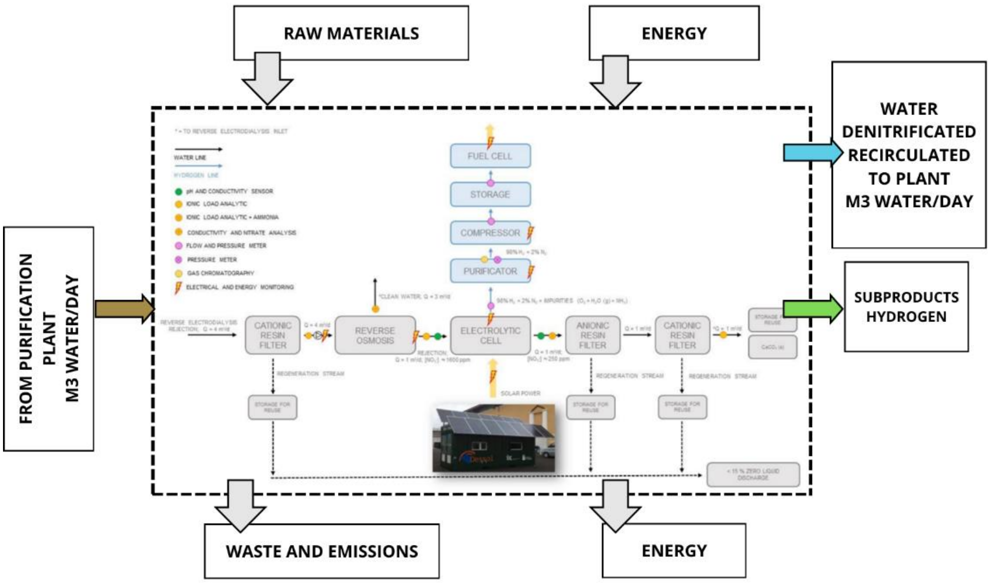

Figure 7: boundary 1 of study, the electrochemical denitrification system. Source: ITE

Boundary 2: Evaluation of the impact of the base case of operation of the DWTP with the incorporation of the new study scenario, which includes the conventional treatment processes and the pilot plant, **cradle-to-gate.** That is why the following objectives will be pursued.

Objective. The objectives are as follows:

- Identify the baseline impact corresponding to the conventional process.
- To identify the impact derived from the new treatment process, considering its repercussion at the DWTP scale and on the inflows and outflows to and from the DWTP.
- Compare the baseline scenario versus the improved scenario, to identify the advantages and disadvantages of the proposed solution and, if necessary, to consider an appropriate mitigation strategy.

Functional unit: It is determined that the functional unit for this study boundary will be 1m^3 of water discharged to the consumption network. The reason is that the system to be studied starts with the entry of water from the well and puts an end to the discharge of water into the distribution network for consumption.

Scope: is going to be considered a **cradle-to-gate** reach since the system starts with the extraction of water from the well (cradle) and ends when the water is poured into the mains for consumption (gate).

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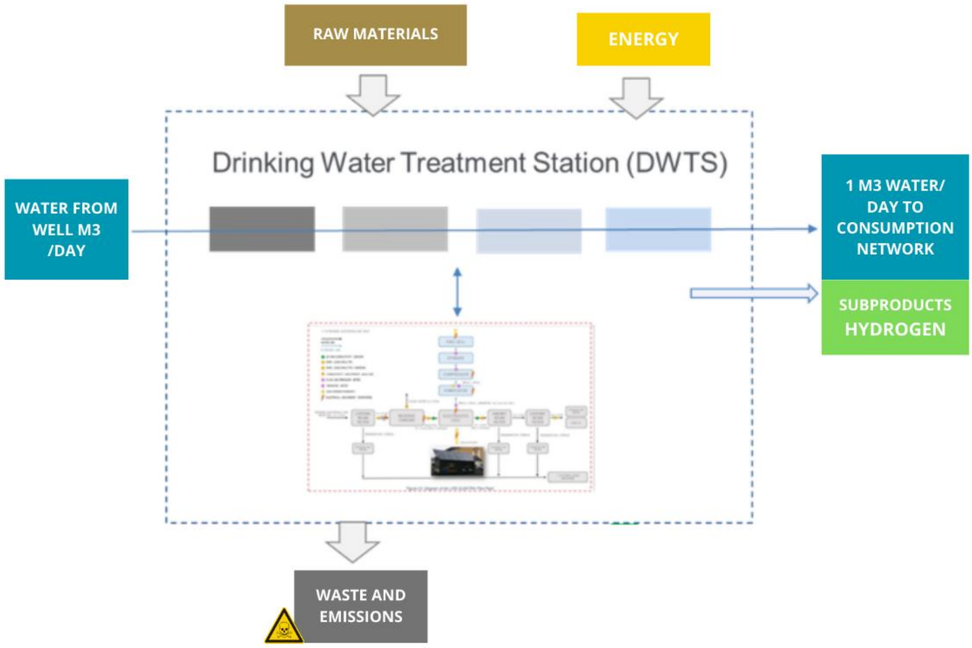

Figure 8: boundary 2 of study with the whole process considered. Source: ITE

These scopes are focused on being able to assess the environmental impact of the process itself, that is, to establish the environmental impact of nitrate removal by electrochemical denitrification. However, the environmental impact of the design of the process itself at the equipment level cannot be ignored.

For this reason, a **cross-cutting analysis of both scopes is proposed** in which the **impact of the equipment necessary in the processes is evaluated** (Figure 9).

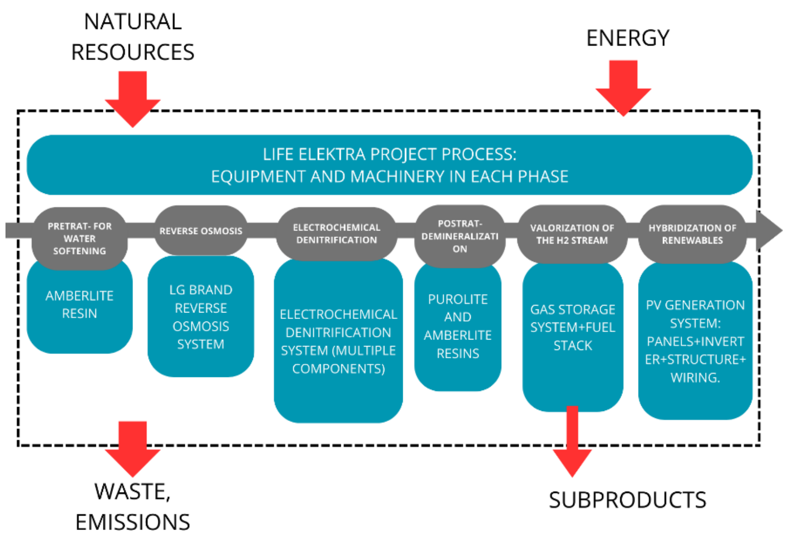

Figure 9: cross-sectional view of environmental impact analysis of the equipment and machinery needed for the denitrification of reject water. Source: ITE

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4.2. Inventory Assessment

Once the system boundaries have been defined, all **environmentally relevant information will be collected** from the stages and processes identified within the system boundaries. More specifically, the aim is to obtain quantitative information on all the inputs and outputs of the electrochemical denitrification process (Boundary 1), as well as the overall process (Boundary 2). The inventory analysis is a material and energy balance of the system, but may include other parameters such as: land use, radiation, noise, vibrations, affected biodiversity, etc.

In general, the information that will be collected can be classified in inputs and outputs of the system:

- **Inputs**: are the consumption of energy and raw material.
- **Outputs**: will be all the products, subproducts and waste generated by the system. These wastes could be emissions to air, discharges to water and seepage to soil.

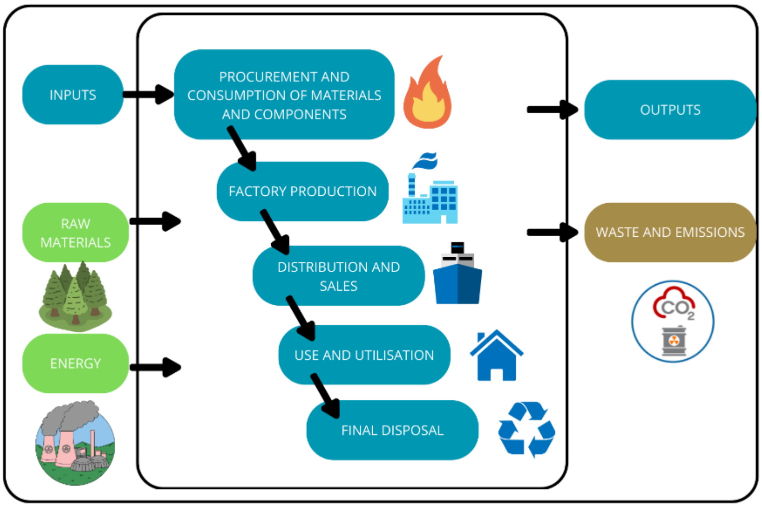

Figure 10: general view of the inventory analysis. Source: INHOBE, prepared by ITE

Therefore, information will have to be sought on the unit processes of the system, that is, the stages of the water treatment process, an inventory of the exchanges with the environment during the process will have to be drawn up, and finally the information obtained will have to be presented in a clear and concise manner.

4.2.1. Identification of inventory needs

As stated in the previous section, two boundaries of analysis are identified. The first one is the analysis of the life cycle of the electrochemical denitrification process of **LIFE ELEKTRA**. This boundary has different stages, and each stage has its own equipment. These machines will consume energy and raw materials and generate waste. This is the approach on which the data collection is based.

The same will apply to boundary 2 in which the plant is understood as a whole. Therefore, an inventory will be carried out for each of the system boundaries. In addition, as mentioned above, a life cycle inventory of the equipment used in the process will be carried out. In other words, information will be collected on the inputs and outputs at the level of machinery needed to carry out the electrochemical denitrification process. Finally, it will be developed:

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Table 3: Different kind of inventories that will be developed. Source: ITE

Inventories			
Type	Boundary	Origin	Data collection
Process	1: electrochemical denitrification	From stages	Environmental relevant information of inputs and outputs
Process	2: already existing system + electrochemical denitrification implementation	From stages	
Machinery and equipment	1: electrochemical denitrification	From manufacture, operation, dismantling	This can only be carried out if sufficient information is available

4.2.2. Data collection method

To ensure that the data collection is carried out in a uniform and complete way, the following preliminary steps will be carried out to define its structure as well as it is indicated in the *Handbook Specific guide for LCI [3]:*

1. Design a process flow chart: a flow diagram of each process will be design in order to know all the units involved. This flow chart will contain all the process units including the relationships between them.
2. Make a complete description of the process: a qualitative description of each stage will be developed to know what is happening, what raw materials it consumes, what kind of energy, what sub-products it generates... etc.
3. Design a list of units: based on the inputs and outputs identified in the process flow, a preliminary list of units of measurement will be make. That list will indicate, at least, if the flows of inputs and outputs are liquid, solid or gas.
4. Start Working on Inventory: collect data from raw materials, energy consumption, products, emissions to air, water and solid waste. The data will be collected in the International System of Units (SI), to minimise conversion efforts and potential errors.

According to the **frequency**, it will be necessary to evaluate along the goal of the study whether multi-annual average data or generic data should be preferred over annual average data as better representing the process. It is also considered that consistent data involving the final implementation of the process and its consumption will be obtained in WP3, as a result of the implementation of each use case, reaffirming the approach of collecting timely information as it becomes available.

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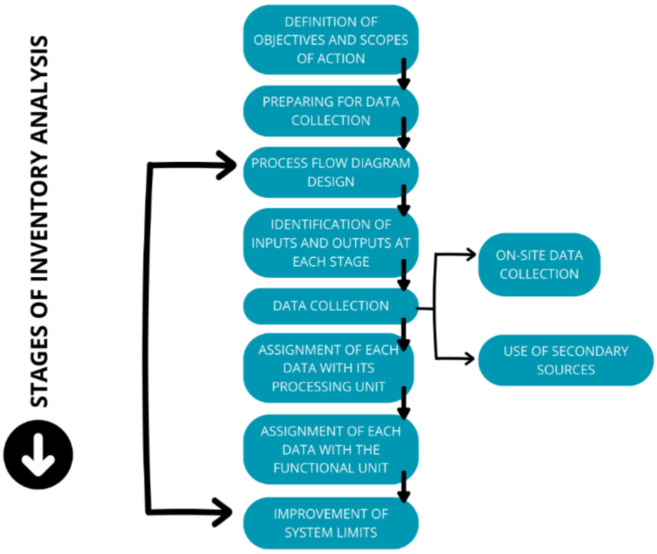

Figure 11:summary of how to make an inventory. Source: ITE.

The information will be collected through primary and secondary data sources:

- **Primary data sources:** will be the data specific to the process being carried out. This data will be collected on-site through monitoring or direct data collection by plant personnel. This is the most reliable source of data but the most expensive to obtain.
- **Secondary data:** Secondary data sources: this is the source of information obtained from public life cycle analysis databases or similar references. This data source is used for information that is too costly or impossible to obtain.

For data collection from **secondary** sources, DDBB incorporated in the SimaPro software will be used. The information obtained will be stored and classified in a clear manner to ensure quick and easy access throughout the project.

The measurement of data collected by process operators will be preferable, if possible and appropriate, and according to the final specifications of the Energy Management and Renewable Hybridization System along with already existing systems in plants where **LIFE ELEKTRA** pilot is implemented. A representative period of information will be proposed for every purpose, involving defining a sufficient number of samples that should be taken.

When access to such information is available, the following tables are proposed to collect it. These **tables are indicative, modifications may be made** throughout the project on what information is needed and how to obtain it, due to the non-sequential nature of the LCA steps.

Table 4: Preliminary data collection table for inventory at process level. Source: ITE

Category	Boundary	Process step	inputs			outputs			
			Energy Consumption (kWh/year)	Water consumption (m^3/year)	Raw materials consumption (kg/year)	Liquid waste (m3/year)	atmospheric emissions (kg X/year)	Materials waste (kg/year)	Subproducts (kg/year)
Process inventory	**boundary 1**	Pretr- water softening							
		Reverse osmosis							
		Electrochemical denitrification							
		Postr- demineralisation							
		H_2 valorisation storage							
		H_2 valorisation conversion							
	boundary 2	Stages of the process							

Table 5: Preliminary data collection table for inventory at machinery and equipment level. Source: ITE

Category	boundary	Process step	machinery / equipment	manufacture		equipment transport	decommissioning	
				inputs	outputs		inputs	outputs
machinery and equipment inventory	**boundary 1**	Pretr- water softening	Simple pumping system	Energy (kwh/year)	Liquid waste (m^3/year)	mass(kg/year)	energy	waste
				water(m^3/year)	Emissions (kg X/year)		water	emissions
				Raw materials (kg/year)	waste (kg/year)	Distance travelled (km/year)	Raw materials	
		Reverse osmosis	Reverse Osmosis System Equipment	…	…	mass		
				…	..			
				…	.	Distance travelled		
		Electrochemical denitrification	Electrochemical denitrification system					
		Postr- demineralisation	Purolita filter					
			Amberlita filter					
		H_2 valorisation	Gas compression system					
			Storage cylinders					
			Fuel cell					
		Hybridisation with renewables, PV system	PV panels					
			inverter					
			wiring					
			structure					

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4.3. Impact Assessment

This is the phase of the LCA in which the inventory of inputs and outputs is translated into indicators of potential environmental impacts on the environment, human health, and the availability of natural resources [4].

Different scientific methodologies are available to carry out life cycle impact assessment. These calculation methodologies are embedded in software tools available for this purpose. **SimaPro** is selected as the main environmental analysis tool and specifically using **ReCiPe** calculation methodology. SimaPro is the Life Cycle Assessment (LCA) software that allows the calculation of the environmental, social and economic impacts associated with a product, service or organisation throughout its entire life cycle. ReCiPe is a method for the impact assessment (LCIA) in an LCA. There are two mainstream ways to derive characterisation factors, that is at midpoint level and at endpoint level. ReCiPe calculates: 18 midpoint indicators and 3 endpoint indicators. Midpoint indicators focus on single environmental problems, for example climate change or acidification. Endpoint indicators show the environmental impact on three higher aggregation levels, being: (1) Effect on human health; (2) Biodiversity; (3) Resource scarcity. Converting midpoints to endpoints simplifies the interpretation of the LCIA results.

The following table shows the indicators at two levels (midpoint and endpoint) that will be obtained after using the recipe methodology (ReCiPe 2016) in the SIMAPRO tool.

Table 6: Environmental categories and indicators with the ReCiPe methodology of calculation. Source: ITE

Environmental impacts categories		ReCiPe Impact indicators (ReCiPe 2016)		
		Midpoints	Endpoints	Unit
Climate change	Considers the potential impact of emissions of different greenhouse gases on global warming over a 100-year time horizon.	Global Warming	**Human health**	**DALY/ kg CO_2 eq**
		Global Warming	**Terrestrial** Ecosystems	**Species.year /kg CO_2 eq.**
		Global Warming	**Freshwater Ecosystems**	**Species.year /kg CO_2 eq.**
Eutrophication of fresh water	Expresses the degree to which different nutrients emitted at European level reach freshwater bodies and their capacity to cause eutrophication effects.	Freshwater Eutrophication	**Ecosystems**	**Species.year /kg P to freshwater eq.**
Eutrophication of sea water	Expresses the degree to which different nutrients emitted at European level reach the oceans and seas and their capacity to cause eutrophication effects.	Marine Eutrophication	**Ecosystems**	**Species.year /kg N to freshwater eq.**
Human toxicity	Expresses the estimated increase in morbidity over the population due to different kinds of emissions on nature	Human carcinogenic toxicity	**Human health**	**DALY/ kg 1,4-DCB**
		Human non-carcinogenic toxicity		**DALY/ kg 1,4-DCB**
Ozone depletion	Calculates the destructive effect of emissions of certain pollutants on the stratospheric ozone layer, considering a time horizon of 100 years.	Stratospheric ozone depletion	**Human health**	**DALY/kg CFC11 eq**
		Ozone formation		**DALY/ Kg NO_x eq**
		Ozone formation. Terrestrial ecosystems	**Ecosystems**	**Species.year /Kg NO_x eq**

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Depletion of minerals and metals resources	Considers the destruction of mineral and fossil resources, taking into account the concrete availability of the resource	Mineral resource scarcity	**Resources**	**USD2013/ kg Cu eq**
		Fossil resource scarcity		**USD2013/ kg oil eq**
Water depletion	Analysis of water use related to local scarcity in different countries	Water consumption	**Human health**	**DALY/m³**
		Water consumption.	**Terrestrial Ecosystems**	**Species.year / m³**
		Water consumption.	Aquatic ecosystems	**Species.year / m³**
Use of land	Refers to the deficit in the quantity and quality of occupied or transformed soil, based on changes in organic matter.	Land use	**Ecosystems**	**Species.year /m2 a crop eq**
Acidification	Describes the potential for changes in the acidity of soil and freshwater bodies resulting from the deposition of certain pollutants emitted into the air.	Terrestrial acidification	**Ecosystems**	**Species.year /kg SO_2 eq**
Particulate matter	It estimates the potential effects on human health resulting from emissions of fine dust particles.	Fine particulate matter formation	**Human health**	**DALY/ Kg PM2.5 eq**
Ionising radiation to human health	It estimates the effects of ionising radioactive emissions on human health.	Ionizing radiation	**Human health**	**DALY/ kBq Co-60 eq**
Ecotoxicity	Measurement of environmental toxicity on water bodies and soil due to different emissions.	Terrestrial ecotoxicity	**Ecosystems**	**Species.year / kg 1,4-DCB**
		Freshwater ecotoxicity		**Species.year / kg 1,4-DCB**
		Marine ecotoxicity		**Species.year / kg 1,4-DCB**

Steps indicated in ISO 14040 [1] and 14044 and European Platform on LCA will be followed with the aim to efficiently associating data with corresponding environmental impact [5].

Table 7: Additional sub-steps of Life Cycle Impact Assessment (LCIA) phase. Source: European Platform on LCA, made by ITE [5]

Step		**Example**
Selection It is necessary to select the impact categories with which the activity will interact.		For example, if gaseous emissions are identified, categories related to air pollution, global warming or air quality will be selected. As well as, if aqueous discharges containing nitrates are identified, eutrophication and human toxicity will be selected.
Classification Classification requires assigning the material/ energy inputs and outputs inventoried to the relevant impact category.		For example, during the classification phase, all inputs/ outputs that result in emissions of greenhouse gasses (e.g. CO_2, methane, etc.) are assigned to the climate change impact category.
Characterisation Characterisation refers to the calculation of the magnitude of the	**How to calculate it** This is carried out by multiplying the inventoried values by the relevant	For example, when calculating climate change impacts, all the greenhouse gas emissions previously inventoried in the LCI are weighted in terms of their impact intensity relative to

contribution of each classified input and output to their respective impact categories, and aggregation of the contributions within each category.	characterisation factor for each impact category considered. The characterisation factors are substance- or resource-specific. They represent the impact intensity of a substance relative to a common reference substance for an impact category (and used to calculate the relative impact category indicator(s)).	carbon dioxide (expressed as kg of CO_2 equivalents).
Normalisation Normalisation is the step in which the life cycle impact assessment results are multiplied by normalisation factors to calculate and compare the magnitude of their contributions to the impact categories, relatively to a reference unit. As a result, dimensionless, normalised results are obtained. These reflect the burdens attributable to a product relative to the reference unit. According the ISO 14040 standard, normalization is an optional phase. Within the PEF / OEF methods, the normalisation phase is mandatory.	**How to calculate it** This is carried out by multiplying the life cycle impact assessment results by normalisation factors relatively to a reference unit.	In the PEF the normalization factors are expressed as impact per capita, based on a global value. For example, the factor for climate change is $8.1 \cdot 10^3$ kg CO_2eq./person.
Weighting Weighting supports the interpretation and communication of the results of the analysis Weighted results of different impact categories may then be compared to assess their relative importance. They may also be aggregated across life cycle impact categories to obtain a single overall score. According to ISO 14040 standard, weighting is an also optional phase. Within the PEF / OEF methods, the weighting phase is mandatory.	**How to calculate it** Normalised results are multiplied by a set of weighting factors (in %) which reflect the perceived relative importance of the life cycle impact categories considered.	For example, the weighting factor in the PEF for climate change is about 21%, representing the relative relevance of this impact compared to the other categories.

It should be noted that the characterisation sub-phase within the impact assessment stage takes place within the SimaPro software interface. The characterisation factors necessary to be able to multiply them by the data obtained in each inventory are part of a database (CFs).

As explained in the report *Supporting information for the recommended characterisation factors for the LCA Assessment Method [6]* from European Commission "The CFs database consists of a database of ILCD-formatted xml files to allow electronic import into LCA software. The LCIA methods are each implemented as separate data sets which contain all the descriptive metadata documentation and the characterisation factors. The database contains moreover data sets of all elementary flows, flow properties and unit groups as well as the source and contact data sets (e.g. of the referenced data sources and publications as well as authors, data set developers, and so on)."

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From the SimaPro tool it will be obtained the environmental impact profile of the process, this is how the project interferes with global warming, air pollution, resource depletion, available water, human health, etc...

4.4. Interpretation of results

The SIMAPRO tool will provide a graph combining information on the impact categories studied and the different phases of the project. In this way it will provide quantitative information on the level of contribution to the environmental categories per project stage.

The phase of interpretation of the results involves drawing conclusions about the environmental impact of the project. For this purpose, several **critical points** will be identified.

Based on the results obtained from SimaPro, we will **identify which stages** of the life cycle contribute most to each of the **impact categories**. And which of the **impact categories** it has been studied are the **most relevant**. That why it will be interesting to combine the inventory analysis with the impact assessment.

The interpretation of the results and, above all, the identification of the stages of the project with the greatest negative impact will guarantee the correct design of the **mitigation plan** for the negative impacts of the project.

In order to facilitate the understanding of the format in which the results are going to be obtained from SimaPro, is shown below the final graph (Figure 12) of the life cycle analysis of a water treatment process divided into different stages made with *SimaPro*.

The following figure shows 4 stages in which the impact of each stage on the environment has been studied as an example of evaluation:

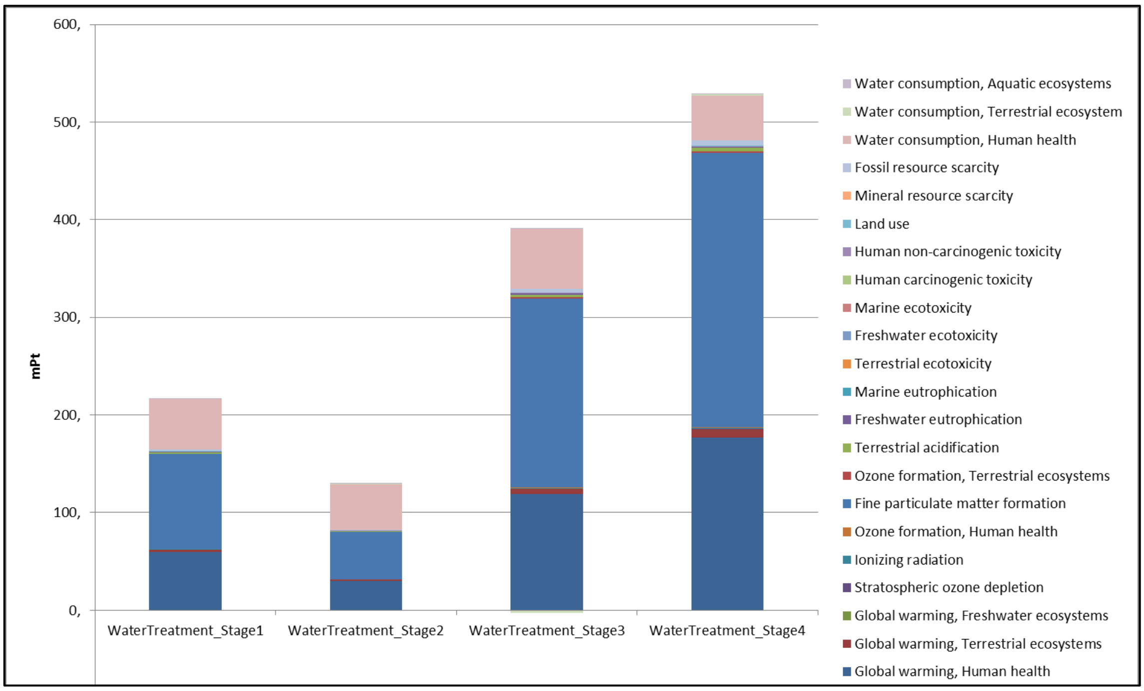

Figure 12: Final graph of a LCA of water treatment obtained by SimaPro. Source: made by ITE.

Based on the above example, it can be interpreted that, for example, stage 4 has the greatest negative impact on the category ecotoxicity of freshwater bodies as well as on the global warming in terrestrial ecosystems. The same approach will be done with the LCA of the **LIFE ELEKTRA** project.

4.4.1. Specific analysis of results

SimaPro tool allows two types of probabilistic analysis: sensitivity analysis and uncertainty analysis. Both will be performed after the impact analysis of the 3 LCAs. On the one hand, the **sensitivity analysis** considers variations of the identified critical parameters to analyse the sensitivity of the life cycle to changes of these parameters in the future. On the other hand, an **uncertainty analysis** consists of identifying, managing and quantifying the uncertainties associated with data sources such as measurement errors, model approximations and input data variability. SimaPro used the Monte Carlo Method to obtain the analysis. The analysis of possible scenarios will form the basis of the mitigation plan and proposals for improvement, as it will allow an assessment of how different variables behave in the face of the proposed changes, allowing a choice to be made between the measures with the greatest potential for improvement.

Based on the characteristic information of the three locations where the project is intended to be implemented, and which will certainly be expanded as it develops, we can advance the following critical points of study of the results of the environmental impacts. It can be anticipated that one of the most interesting impact categories will be **water depletion**. It is being observed that there is an increasing trend of prolonged periods of drought due to climate change resulting from global warming. This change in meteorology is applicable to all three pilot plants.

A relevant example to illustrate the importance of impact analysis refers to the cumulative warming of the Mediterranean basin over the study period (1982-2022) is almost 1.6 ºC, which directly affects the target locations of Gandía and Malta. An increase in temperature in the Mediterranean basin translates into less precipitation, more heat, and therefore more evapotranspiration from the land. Therefore, these two locations are likely to have greater difficulty in having their aquifer reserves regenerated every yearly water cycle. In the case of Malta, the water for consumption comes directly from wells, and in the case of Gandía, the rejection water to be treated to eliminate nitrates also comes from the exploitation of aquifers, so it will be interesting to evaluate the category of water depletion in both cases. In the case of Gran Canaria, 90% of the water comes from the desalination plant and 10% from underground water reserves, so in this case, the potential impact will foreseeably be lower.

Another interesting environmental category to evaluate will be the **eutrophication** of both fresh and marine water bodies. As mentioned in previous sections, the eutrophication of water bodies is considered to be the greatest threat to the imbalance of aquatic ecosystems. Furthermore, there is bibliographic information available prior to the project that shows that the aquifers that are exploited for consumption in the three planned locations are already contaminated by nitrates. This makes it evident that serious problems with the eutrophication of ecosystems exist, so any improvement in this impact category will be beneficial to the environment.

Finally, it is expected that there will be differences in the environmental impacts derived from the **energy consumption** of each process, as it is expected that there will be differences between the plants with respect to their energy needs. By studying the phases of electrochemical denitrification, it is at least expected that there will be differences in energy consumption in the reverse osmosis phase, which is responsible for reaching the optimum concentration of nitrates to optimise their elimination. The inlet water to the denitrification process in Malta and the Canary Islands has lower levels than that of Gandia, so differences in the associated energy consumption are likely to be observable.

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5. S-LCA Methodology

In 2004, an initiative of the United Nations Environment Programme (UNEP) and SETAC (UNEP/SETAC hereafter) created a working group on the integration of social indicators into LCA. These meetings involved experts from various disciplines and representatives of various stakeholder groups. The initiative resulted in the publication in 2009 of the "Guidelines for a Social Product Life Cycle Analysis" (UNEP, 2009) [7].

According to the **Guidelines elaborated by UNEP/SETAC, the SLCA** is "a social impact assessment technique that aims to assess the social and socio-economic aspects of products including extraction, raw material processing, manufacturing, distribution, use, reuse, maintenance, recycling and disposal" [7]. Like the LCA, which is regulated by different ISO standards, the SLCA is carried out in four phases:

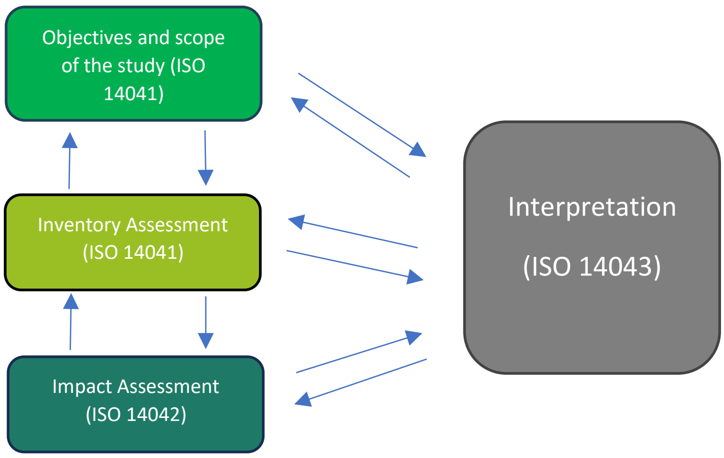

Figure 13: Different stages of a SLCA according to ISO 14040. Source: ISO 14040 [1], made by ITE

5.1. Objectives and scope of the SLCA

In the first phase, the **function of the process** (in other words, the role that the project plays for consumers, both technically and socially), the **functional unit** (the unit of reference for the analysis, which defines and quantifies the function that the product or system under analysis fulfils) and all the **stages of the life cycle** are identified [7].

The primary objective of the LCA-S is to promote the improvement of the social conditions and socioeconomic performance of the denitrification process proposed by **LIFE ELEKTRA** throughout its life cycle and for all the people involved, directly and indirectly.

As a secondary objective, it is intended that the decision-maker takes the necessary measures to reduce or enhance it and thus increase its social performance.

This analysis will determine where situations occur that can be considered a problem, a risk, or an opportunity in relation to a social issue classified as important according to different international conventions.

Given that the social and cost analysis are based on the environmental LCA in terms of the study system and scopes, it is determined that two scenarios will be studied with the intention of establishing a comparison:

- The current one where water potabilization is carried out without solution for the rejection flow with high nitrate concentration.
- The new scenario where the implementation of the electrochemical denitrification process is already incorporated to the current drinking water treatment system and the plant is analysed.

As in the environmental analysis, two system limits will be studied:

Boundary 1: denitrification process (**LIFE ELEKTRA**). The study of this process, as explained in previous sections, will include a gate-to-gate scope. From the time the reject flow enters the plant until it is incorporated at the plant headworks.

- **Functional unit**: 1m^3 of water recirculated to the plant headworks.
- **Stages of the life cycle**, since the social impact will be studied at the process stage level:

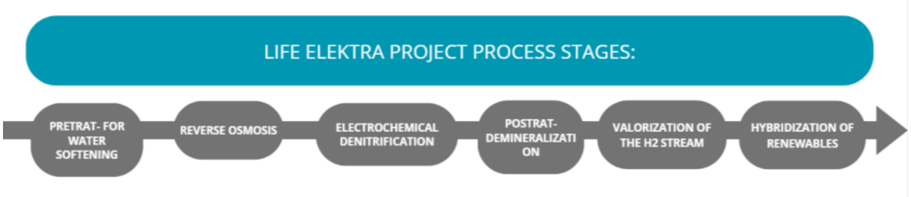

Figure 14: Stages of the life cycle of LIFE ELEKTRA. Source: ITE

As well as the environmental approach, the impact on the population of all the previous phases necessary to implement the denitrification plant of the project cannot be ignored. This approach is mainly justified by the premise that, in a globalized world where the extraction of materials and the assembly of equipment normally takes place in different countries, the social situation varies. It is not the same to manufacture a computer entirely in Europe, with all its phases under European legislation, than to extract the minerals in Somalia, process them in China, assemble them in Germany and end up using them in Spain.

As the life cycle methodology contemplates the inclusion of only those stages that have a significant impact, within limit 1 (electrochemical denitrification process) a social impact study is proposed **for at least the following stages** of the equipment used.

- Equipment and machinery life cycle stages:

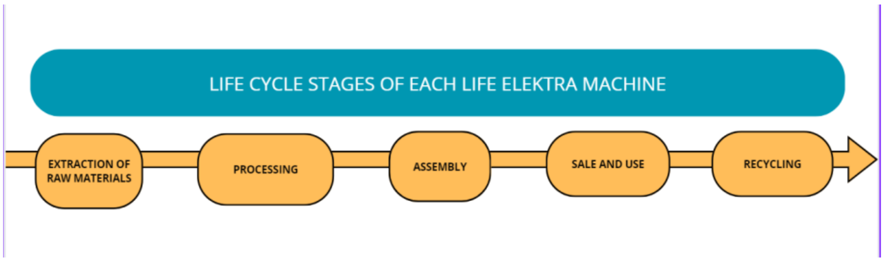

Figure 15: Equipment life cycle stages to study. Source: ITE

Boundary 2: Evaluation of the impact of the base case of operation of the DWTP with the incorporation of the new study scenario. This limit will have a cradle-to-door scope, that is, from the time the water is extracted from the well until the water is discharged for consumption.

- **Functional unit**: 1m^3 of water discharged to the consumption network.

- **Stages of the life cycle** as the social impact is going to be studied at the **level of process** stages:

5.1.1. Impact categories and stakeholders' identification

The SLCA is based on impact categories derived from issues of social concern. The Guidelines propose the following impact categories [7]:

Table 8: social impact categories proposed by UNEP/SETAC.

Social impact categories proposed by UNEP/SETAC		
Human rights	Health and safety	Gobernance
Work condition	Cultural heritage	Socioeconomic impact

Impact categories refer to very abstract and general concepts, and are therefore broken down into impact subcategories, which are socially significant issues or attributes. The subcategories can be classified according to impacts or according to stakeholders, and the two classifications are complementary.

Stakeholders are groups of social actors who have a shared interest due to their similar relationship with the system under analysis (e.g. workers, consumers, suppliers). The LCA does not consider social pressures determined by environmental impacts, because the latter are already included in the LCA [7].

The main categories of stakeholders proposed by the Guidelines are as follows:

Table 9: Stakeholders categories proposed by UNEP/ SETAC.

<table>
<tr><th colspan="3">STAKEHOLDERS CATEGORIES</th></tr>
<tr><td rowspan="4">PRIMARY</td><td colspan="2">Workers</td></tr>
<tr><td colspan="2">Consumers</td></tr>
<tr><td>Finals</td><td>Consumers for each stage of life cycle</td></tr>
<tr><td colspan="2">Value chain actors</td></tr>
<tr><td rowspan="3">SECONDARY</td><td colspan="2">Local community</td></tr>
<tr><td colspan="2">Society</td></tr>
<tr><td>Nacional</td><td>Local</td></tr>
</table>

To these can be added other categories of stakeholders (NGOs, the state or future generations) or other differentiations or subgroups (e.g. shareholders and business partners) [7].

The following diagram (Figure 16) shows the succession of categories and subcategories proposed by the UNEP/SETAC working group that elaborated the Guidelines. It can thus be seen how the broad categories of social issues are concretized into specific subcategories depending on the type of social actor under study. An impact category can be related to different categories of stakeholders, and a category of stakeholders can be affected by different impact categories.

Throughout the project, by observing and studying its development, the necessary impact categories and subcategories will be selected.

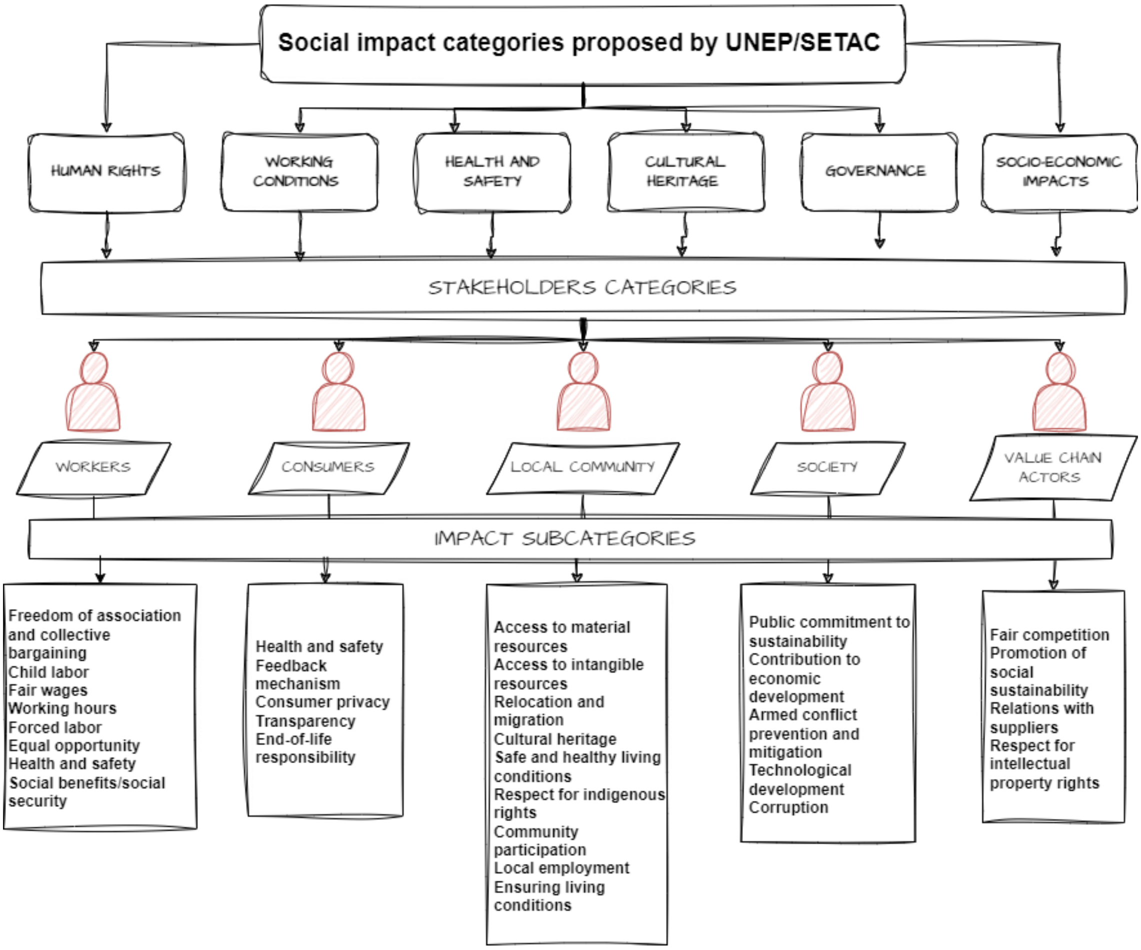

Figure 16: Relation between the categories, stakeholders, and subcategories of social impact. Source: ITE

5.1.2. Data collection method

This phase also determines the methodology to be followed to obtain the necessary data and information. The authors Hauschild et al. (2008) and Benoît et al. (2010) propose combining the following methodologies for data collection [7]:

- **Bottom-up** information obtained through field analysis. This allows the information available and the perspectives of all stakeholders to be taken into account as it would consist of field interviews asking stakeholders about the different subcategories.
- **Top-down** information ensures minimum acceptability criteria for company activities as it is based on information on, for example, what has been agreed in international treaties.

Once it has been determined the limits of the system and the method it is necessary to define from where it is going to take the information. The information could be generic or specific [8]:

- <u>Generic information</u> is information that describes processes in general. It can be taken from an organisation in the same sector. It does not require the participation of those involved.
- <u>Specific information</u> is information that defines more specific processes where those involved are directly affected. This information can be obtained through forms, interviews, surveys, etc.

Fieldwork may include **field visits**, **interviews**, **questionnaires**, **organization of focus groups**, **review of documentation from the company**, **authorities**, **NGOs** or trade union organizations. Top-down information can be obtained from international treaties on human and labour rights, such as the **Declaration of Human Rights and the Conventions** of the **International Labor Organization** [7].

It will be interesting to answer these following questions in order to clarify the information needed to be collected before starting the inventory.

1. Where are located the processes?
2. Which are the companies involved in each stage of the processes?
3. Who is involved in each process?

By the end of the first stage, it should have enough information to be able to determine the following sections:

Figure 17: Check list by the end of the first stage of the SLCA. Source: ITE

5.2. Inventory Assessment

In this second phase, the data necessary to carry out the analysis of social impacts, namely **the inventory**, is collected. The perfect way to achieve this, would be to specifically analyse how each stage of the life cycle affects to the stakeholders. This would be done by surveying all the places where the project produces social impacts. However, it is **not realistic** to propose an inventory based only on visits as it would imply very high costs and a very extensive timing.

Therefore, it must first be established which type of information to obtain from primary sources and which from secondary sources. To make this decision, a method proposed by the author Hauschild [9] to combine information on the **social hotpots** and on the **activity** will be used.

Social hotspots are **stages of the life cycle** that, due to the production processes or local conditions, have a high probability of generating a high social impact, positive or negative. The analysis provides information on where the most relevant social impacts are most likely to occur. For example, one social hotpot would be the extraction of the minerals to manufacture the different machines because of the main mines of rare minerals are in African countries where

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the human rights are not guarantees. Social Hotspots Data Base tool (Figure 18) will be used to identify social hotspots in the project.

As can be seen in the Figure 18, the stage of the process (electronic equipment), the category of impact (labour right) and the subcategory (child labour) could be indicated, and the tool will show the impact in the society per country.

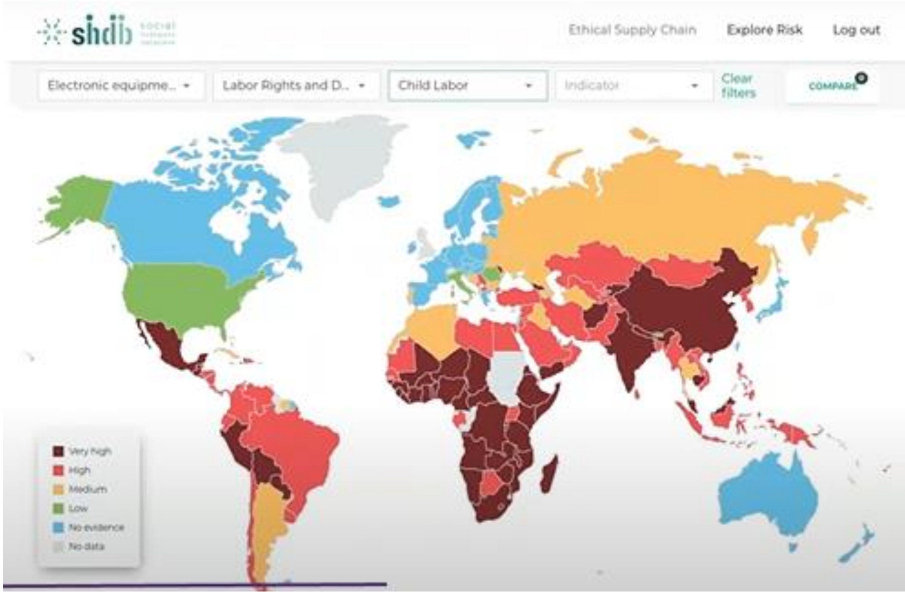

Figure 18: preview of the social hotpots database tool. Source: SHDB.

The **activity variables** are the solution proposed by the UNEP/SETAC Guidelines [10] to assign a weight to the different stages of the life cycle when using qualitative or semi-quantitative data, which cannot be referred to the functional unit directly. As activity variables its proposed **working hours and added value**.

In the LCA the environmental impacts are related to the functional units of the process, but in SLCA the social impacts are more related with the company organisation and its relationship with the stakeholders, than the functional units. For example, the impacts included in the subcategory "fair pay" depends more on the own political of the company than productive process. That's why activity variables are necessary.

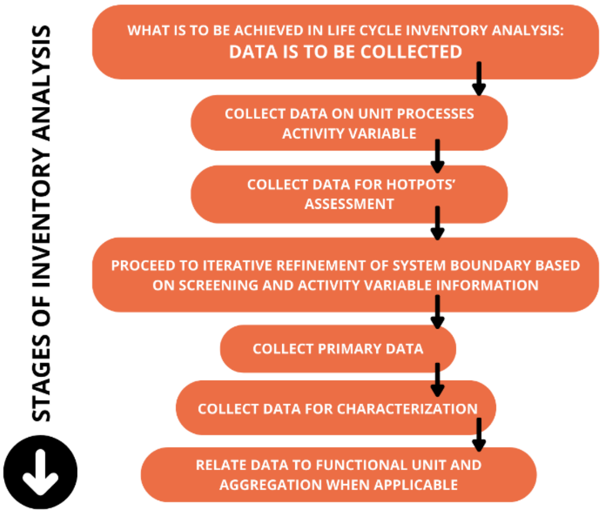

Figure 19: Summary of the stages to make the inventory assessment. Source: ITE

Once the necessary information is available to know the importance of each process and for which processes it will be needed specific information, it will be possible to proceed with the search of information.

Generic information can be obtained from:

- Bibliographic reviews.
- Internet search (national or regional statistical institutes, UN, World Bank, UNDP, OECD, Social Hotspot Data Base...).

Specific information:

- Audits of organisations (GRI).
- Interviews.
- Surveys.
- Questionnaires.
- Participatory methodologies.
- Field studies.

To make an approach on how to start to collect the information to design the inventory, the following table could be useful to start. This is a suggestion that could be modified during the project due to the non-sequential nature of the SLCA.

Table 10: suggestion of how to make an inventory of social impact. Source: UNEP/SETAC (2009) [10], made by ITE.

Life cycle stage	Stakeholders	Impact categories	Subcategories	Indicators	Inventory data
pretrat- for water softening	Workers	Human rights		TRADE UNION PRESENCE IN THE COMPANY	2 TRADE UNIONS
		Working condition	Freedom of association and collective bargaining		
			Child labor	NUMBER OF TRADE UNION DELEGATES AND MEMBERS	1 DELEGATE 15 MEMBERS
			Fair wages		
			Working hours	TYPE OF WORKING DAY/ CONTRACT	40 HOURS PER WORKER
			Forced labor		
			Equal opportunity		
			Social benefits/social security		
			Health and safety		
		Helth and safety			
		Cultural heritage			
		Governance			
		Socio economic repercussion			
	Local community	Impact categories			
	Society	Impact categories			
	Consumers	Impact categories			
	Value chain actors	Impact categories			
Reverse Osmosis	stakeholders				
Electrochemical denitrification	stakeholders				
postrat- demineralization	stakeholders				
...	stakeholders				

5.3. Impact Assessment

The Life Cycle Impact Assessment phase consists in a set of actions summarized below:

1. To select the impact categories and subcategories, and the characterization methods and models.
2. To relate the inventory data to particular sLCIA subcategories and impact categories (classification).
3. To determine and/or calculate the results for the subcategory indicators (characterization) [10].

As indicated in the environmental part, SimaPro software will be used to carry out the impact analysis phase using the ReCiPe methodology.

Impact Assessment is the third phase of a S-LCA. The purpose of sLCIA is to provide a combination of aggregating some inventory data within subcategories and categories and making use of additional information, such as internationally accepted levels of minimum performance, to help understand the magnitude and the significance of the data collected in the Inventory phase [10].

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As with the environmental impact analysis phase, the following table show the phases to make the inventory assessment:

Table 11: Phases of the inventory assessment from Guidelines for Social Life Cycle Assessment of Products [10]. Source: ITE

Step		Example
Selection It is necessary to select the impact categories, subcategories according to the inventory data collected		For example, if it has been identified that there are machinery components that are imported from countries outside the European Union, it is likely that the category "working condition" can be selected.
Classification The classification step is the part where the Inventory results are assigned to a specific Stakeholder Category and/or Impact Category. As in E-LCA, the classification is implicitly part of the Characterization Models (Social and Socio-economic Mechanisms) development.		For example, during the classification phase, data obtained in the plant process phases requiring labour staff will be classified under the category "working conditions" and in the subcategories "working hours" and "freedom of association".
Characterisation The calculation of indicator results (characterization) involves the conversion of LCI results to common units and the aggregation of the converted results within the same impact category. This conversion uses characterization factors. The outcome of the calculation is a numerical indicator result.	**How to calculate it** A **scoring system** may be used to help assess the “meaning” of the Inventory data, based on performance reference points. This provides an estimation of the impact. In contrast to E-LCA, the S-LCA scoring and weighting step might be undertaken at the characterization step (instead of interpretation), which can also be designated as the meaning assessment step.	For example, when calculating the social impacts on child labour in relation to mineral extraction in African countries, the calculation of the intensity of the impact of the use of minerals for processing will be carried out.
Weighting Converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices; data prior to weighting should remain available phase.	**How to calculate it** Normalised results are multiplied by a set of weighting factors (in %) which reflect the perceived relative importance of the life cycle impact categories considered.	…

It should be noted that the characterisation sub-phase within the impact assessment stage takes place within the SimaPro software interface. The characterisation factors necessary to be able to multiply them by the data obtained in each inventory are part of a database (CFs).

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5.4. Interpretation of results

Finally, in the interpretation phase, the most significant impacts are determined, the results of the research are evaluated, conclusions are drawn, recommendations are proposed, and a final report is prepared.

Life Cycle interpretation is the process of assessing results to draw conclusions [11]. ISO 14044[1] (2006) defines three main steps:

1. Identification of the significant issues.
2. Evaluation of the study (which includes considerations of completeness and consistency).
3. Conclusions, recommendations, and reporting.

Therefore, in the same way as the results are obtained in the environmental analysis, the software tool used will show graphs relating the phase of the project studied with its level of impact for each social category identified. This will again provide the necessary information to identify which phases of the process are most critical and therefore have the greatest potential for improvement. In the same way, conclusions will be drawn on how the development of the project positively affects the local level, that is by eliminating a problematic pollutant from drinking water.

Finally, after the interpretation of the results and identification of the main problems associated with the project, it will be possible to develop a mitigation plan to improve the social performance of the **LIFE ELEKTRA** project.

5.4.1. Specific analyses of results

As indicated in the environmental LCA section, sensitivity and uncertainty analyses shall be carried out. The analysis of possible scenarios will lay the foundations for the mitigation plan and improvement proposals, as it will make it possible to assess how different variables behave in the face of the proposed changes and to choose between the measures with the greatest potential for improvement.

In the social field, it is expected that it will be interesting to evaluate the impacts associated with the generation of employment during the different phases of the project and in the populations where the plants are to be implemented. It will also be interesting to evaluate the categories of general social benefit, especially those related to an increase in social awareness of water use and the impacts on the economic development of the area. It will be assessed whether the locations where the project is to be implemented experience changes in the quality of life of the population as a result of the effective operative cost of generating drinkable water (note that this technology rivals with other more expensive technologies such as Reverse Osmosis), and if improvement in the ecological capital of their environment have been reached.

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6. LCC Methodology

Parallel to the environmental assessment, the economic assessment of the project will be carried out, considering the two scenarios under the operating conditions proposed by **LIFE ELEKTRA**. The Life Cost Cycle methodology will be used to evaluate all the economic costs associated with the full life cycle of the pilot prototype, including direct costs and environmental externalities, according to EN ISO 14008:2020. The procedure used for the economic evaluation will be analogous to that used for the environmental assessment in terms of scope (functional unit, system boundaries, scenario comparison, etc.) [12].

Therefore, the methodology of the LCC presents the following outline, again aligned with two previously presented approaches:

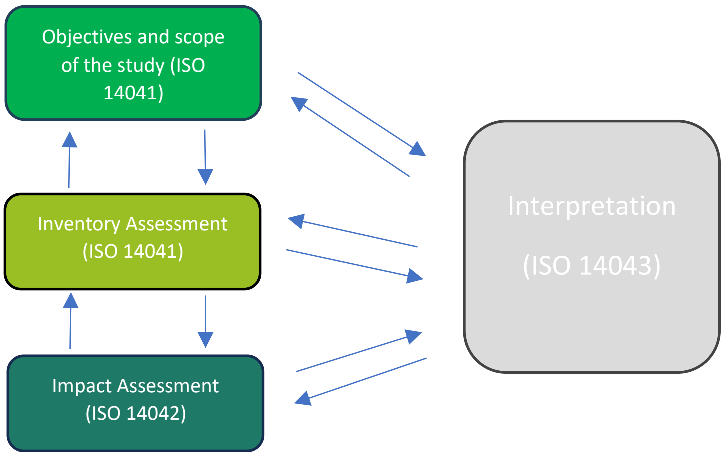

Figure 20: Different stages of a LCC according to ISO 14040. Source: ISO 14040, made by ITE.

It is intended to assess the costs of all actors involved in the product life cycle, therefore environmental LCC methodologies would be used, which also include external environmental costs that are expected to be internalised in a decision-relevant period. At this point when it is referred to as life cycle costing taking into account environmental externalities, then it is referred to as LCC-environmental methodology, based on the structure of ISO-14040:2006 and proposed in the UNEP-SETAC Guide, and in the LCC documents published by SETAC [12].

The following is a brief description of the LCC-environmental methodology, which will be used as a reference throughout this document.

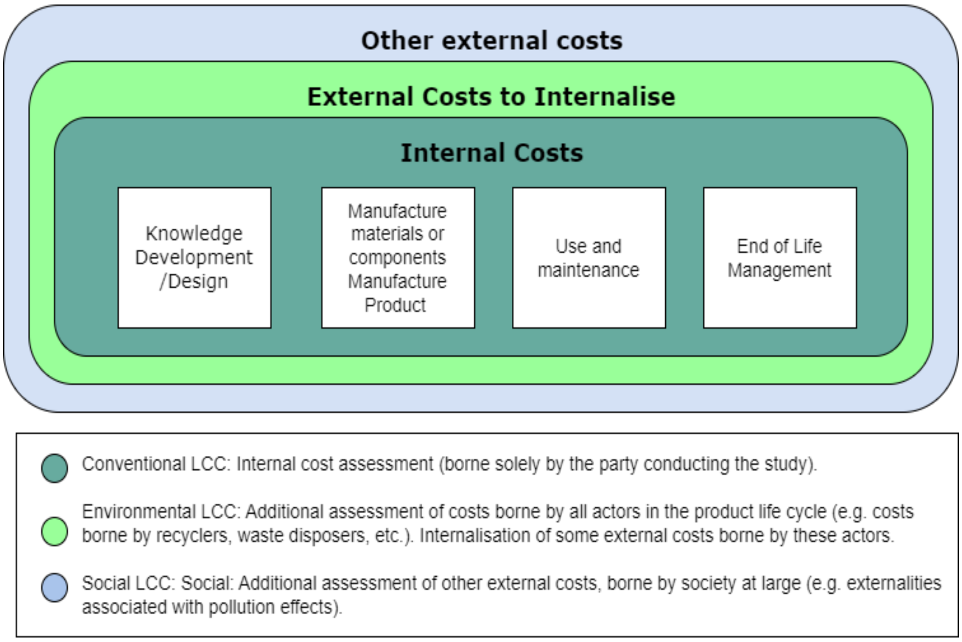

Figure 21: Different kind of life cycle cost assessment: Source IHOBE [12], made by ITE.

6.1. Objective and scope of LCC

The objective of conducting a life cycle cost analysis of the project is to understand the importance of the overall life cycle cost of the **LIFE ELEKTRA** project and to identify the variables that make up the life cycle cost. In the same way as explained in the environmental and social assessment, this first stage defines:

- The **objective**, which should define the intended use and rationale for conducting the analysis, the audience, and stakeholders to whom the results will be communicated and whether comparisons with other products will be made public.
- The **scope** should be adequately defined to ensure compatibility and capability with the above objective. This will be analogous to environmental analysis.

Therefore, as explained in section *Objectives and scope of the SLCA* it is determined that two scenarios will be studied with the intention of establishing a comparison:

- The current one where water potabilization is carried out without solution for the rejection flow with high nitrate concentration.
- The new scenario where the implementation of the electrochemical denitrification process is already incorporated to the current drinking water treatment system and the whole plant is analysed.

Below is a summary table of the limits and scopes to be studied that will be common to the cost assessment:

Table 12: Summary of the boundaries of the system. Source: ITE.

<table>
<tr><td colspan="4">Boundary 1: Cost Cycle Assessment of the denitrification process of the DWTS reject water for recirculation to plant headworks.</td></tr>
<tr><td>Objective</td><td>Functional unit</td><td colspan="2">Scopes Gate to gate</td></tr>
<tr><td rowspan="2">The new treatment process (pilot plant) will be analysed separately, in order to have perfectly identified and detailed both positive and negative impacts related to its implementation.</td><td rowspan="2">1 m³ of recirculated water. The system to be studied starts with the entry of the reject water with high nitrate concentration and ends with the outlet of the denitrified water which is re-injected into the drinking water treatment plant.</td><td colspan="2">Process level</td></tr>
<tr><td colspan="2">Machinery and equipment level</td></tr>
<tr><td colspan="4">Boundary 2: Cost Cycle Assessment of the conventional treatment process (purification process) and the pilot plant (denitrification process).</td></tr>
<tr><td>Objective</td><td>Functional unit</td><td>Scope</td><td>Scenarios</td></tr>
<tr><td>Compare the baseline scenario versus the improved one, to identify the advantages and disadvantages of the proposed solution and, if necessary, to consider an appropriate mitigation strategy.</td><td>1m³ of water discharged to the consumption network. The system to be studied starts with the entry of water from the well and puts an end to the discharge of water into the distribution network for consumption.</td><td>cradle-to-gate</td><td>Comparing the initial situation (without implementing the Denitrification system) and the new one (the conventional treatment process and the pilot plant).</td></tr>
</table>

According to the Guide for the joint application of *Environmental Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) proposed by INHOBE [12]*, the following sub-phases are preparatory to the collection of the necessary information.

Table 13: previous subphases to start collecting the inventory. Source: INHOBE [12], made by ITE.

Preparatory steps for the inventory
Definition of the system's stages
As with the social analysis, in this case it will be necessary to distinguish the unitary stages of the process. It consists of establishing those stages of the product life cycle that are necessary and relevant to obtain a sufficient degree of confidence in the results, in accordance with the objective of the study. The system boundaries should be the same for all three study approaches, but the stages need not be the same. For example, it is common for the Design and I+D phase of a product to have a relevant weight in the overall costs of the product, but for an LCA, this stage usually does not represent a significant environmental impact.
Cut-off criteria
The cut-off criteria are used to define which costs are included in the assessment. The cut-off criteria should therefore be described, as well as the assumptions on which they have been established. Typically, it consists of discarding costs that represent a lower % than the set cut-off. Such cut-off criteria should be clearly described, especially if a critical review is planned. The choice of cut-off criteria is relevant as it will set the resources needed for the collection of data for the Inventory phase. Very strict cut-off criteria would imply the need to collect information from many inputs and outputs. Very broad cut-off criteria would imply that the results would not be representative.
Impact categories and methodology
In the case of LCC, the only impact most frequently considered is monetary (e.g. euros at current value). Therefore, the reference currency and the time reference (year of the study) need to be fixed. In addition, the "discount rate" (and possibly "escalation rate" for certain flows), which will be used to calculate the present value of future costs/benefits, must be defined at this stage. This discount rate may vary depending on the perspective indicated in the objective of the study (e.g. view of the manufacturer, consumer, etc.). On the other hand, the cost breakdown structure **(Cost Breakdown Structure** -CBS-) should be developed to

facilitate the consistent collection of data along the full life cycle and which can also be aggregated along the life cycle., e.g. "**labour costs", "transport costs", "energy costs", "material costs**", etc. In this case, the impact categories of LCA and LCC are clearly different, in line with the vision of both methodologies. This difference means that the Impact Assessment phase does not actually exist in the LCC, as it is simply the aggregation of the costs identified in the Inventory Analysis phase
Data requirements and data quality
As in the case of LCA, primary data are included for the stage of the life cycle where the organisation carrying out the study is directly involved, and secondary data for the rest. In this case, there are not many cost databases, and it is sometimes necessary to consider directly the "purchase cost" of the flow as a benchmark for the associated upstream costs. However, these reference costs can be highly variable (e.g. depending on the country, currency exchange rate, economic situation, etc.).

At the end of this phase, following steps must be defined:

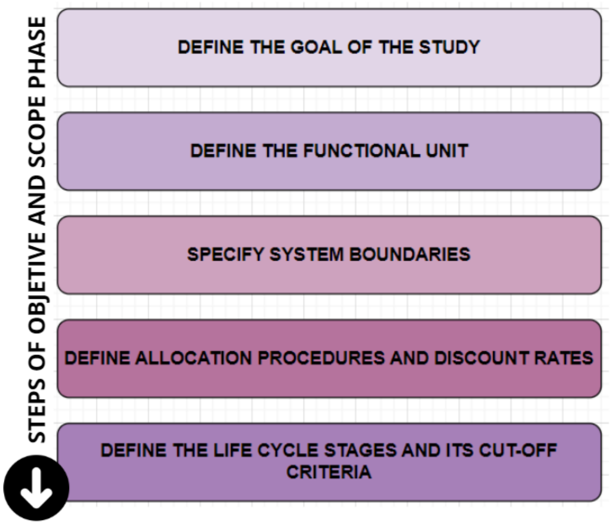

Figure 22: Steps of objective and scope phase of LCC. Source: ITE

6.2. Inventory assessment

This phase involves data collection and calculation procedures to quantify the inputs and outputs of the product system defined in the study. Therefore, the first step is to define the product system to be analysed, dividing the main stages of the life cycle into unit processes, and identifying their inputs and outputs [12].

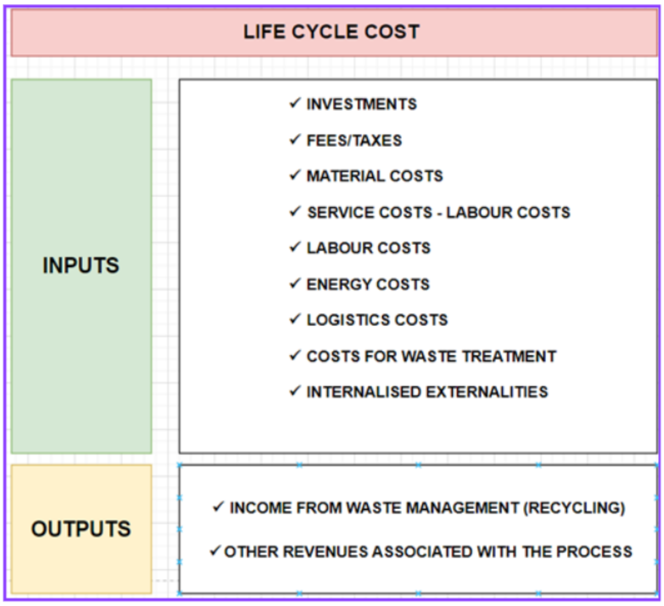

Figure 23: Inputs and outputs of the LCC. Source: INHOBE [12], made by ITE.

Once these inputs and outputs are collected, they should be referred to the functional unit defined in the scope of the study. The following section indicates how to develop the inventory analysis for LCC based on the concept of "cost element" proposed in the UNE-EN 60300-3-3:2009 Standard (adaptation of the International Standard IEC 60300-3-3-3:2004) [12].

6.2.1. Breakdown of the LCC into cost elements.

The ISO standard proposes to break down the life cycle cost analysis of the product or process into what it calls cost elements. These cost elements are the simple way to break down the entire life cycle to extract the necessary information on economic costs in an orderly and concise manner. This is the method to be used in the data collection. To perform a cost breakdown analysis, you need a cost breakdown structure (CBS), which is a hierarchical map of your project costs.

Identification of unitary phases of the life cycle

The first step is to break down the product or service into stages that have their own characteristics and are relevant to the LCC study. It is proposed the following stages: development, production, use and end-of-life. Each of these can be subdivided.

The costs associated with each stage of the project are then identified. Therefore, it will start by identifying the different phases of the project and in each of them identifying the unit costs (costs are inventoried on a unit process level [12]).

Identification of costs by unit phase.

In general, there are four types of costs essential to create a complete cost breakdown structure: labour, material, equipment and overhead costs. These four groups may be subdivided into further costs as they are identified.

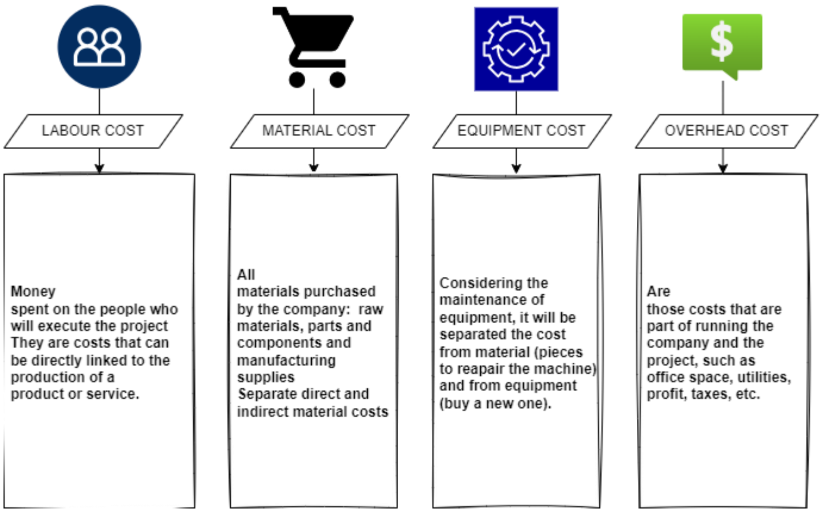

Figure 24: The four main groups of cost. Source: ITE

Selection of cost categories

The selection of the cost categories to be considered in the LCC study (the cost breakdown structure) is one of the most challenging parts of the methodology, as it will have a direct influence on the representativeness of the results and the amount of resources to be used to collect the data associated with these categories [12].

Therefore, at this stage it must be decided which costs are to be considered and how the data will be organised. It should be considered that some costs can be relatively easily assessed by the stakeholder (e.g. direct manufacturing costs such as energy, materials, labour costs, etc.), but others may be more difficult to assess (e.g. waste management costs, or pollution control elements). It should also be assessed which external costs are expected to be internalised in the reference period of the study [12].

Another aspect to consider is that the LCC study should aggregate the costs of different actors in the value chain of the analysed product, which may have different relevant cost categories. The following table shows proposed cost categories for a process, given its general life cycle stages.

Table 14: Proposal of life cost categories of impact. Source: ITE

Life cycle stage	LCC Cost categories
Development	I+D+I cost (manufacturer) Design cost/ engineer (manufacturer) Validation cost (manufacturer) Marketing cost (manufacturer)
Production (of water?)	Manufacture cost (manufacturer) Logistic cost (manufacturer) Invest (manufacturer) Sales cost (manufacturer/consumer) Materials cost
Use (of water?)	Energy and water cost Maintenance cost Transport cost (consumer?)
End of life	Wastes treatment costs (recycler)

The following figure illustrates the result to be obtained after the design of the Cost Breakdown Structure and has been adapted to the case of **LIFE ELEKTRA**. As can be seen, the procedure consists of combining the project stages identified in the development of **LIFE ELEKTRA**, in this case the reactor where the electrochemical denitrification will be carried out has been taken as an example. At the same time, it is combined with the information of the cost categories and the labour cost of the personnel has been taken as an example. Finally, these two variables are related to the phases of the life cycle, in this case the reactor manufacturing phase has been selected. So finally, the cost element is extracted: Labour costs associated with the people who manufacture the electrochemical denitrification reactor.

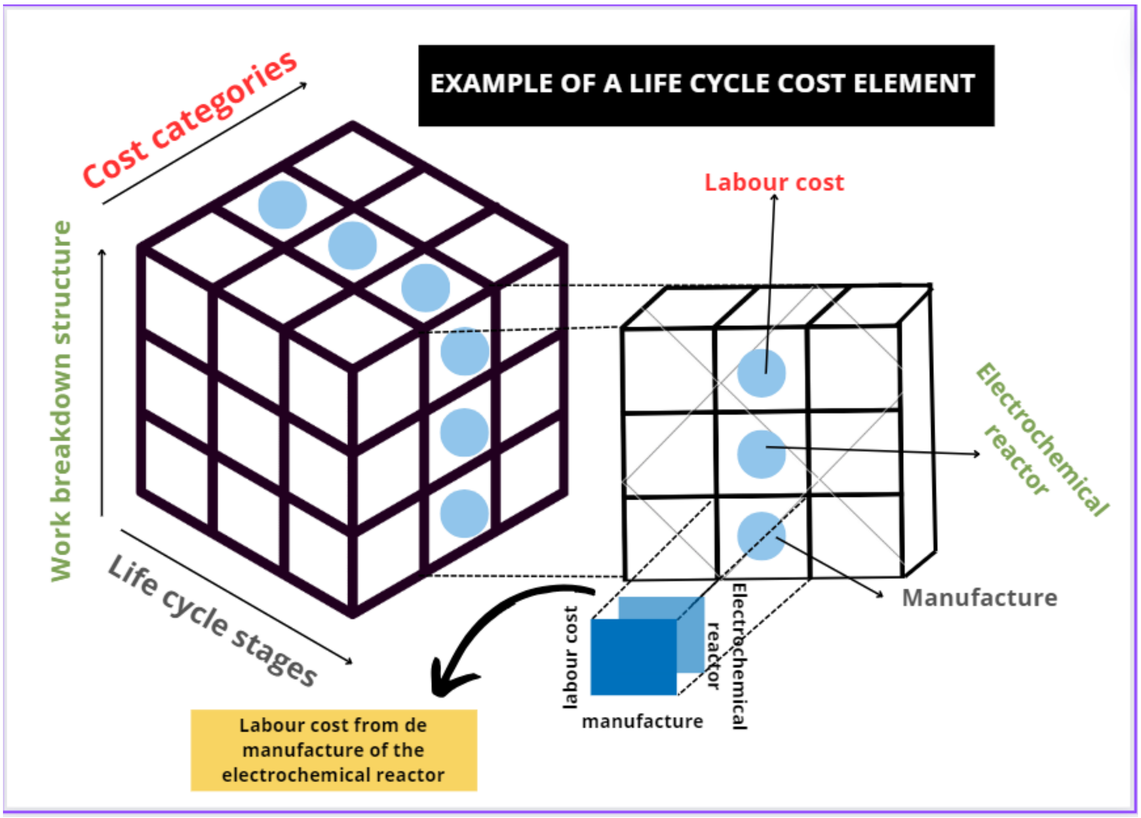

Figure 25: Example of the extraction of a life cycle cost element apply to the LIFE ELEKTRA project. Source: Towards a Life Cycle Sustainability Assessment, UNEP [13]. Made by ITE.

6.2.2. Data collection method

As with LCA and SLCA there are two sources of data, primary and secondary. Applied to cost analysis they are:

1. **Primary data**. These are the data that the actor involved can obtain directly from the analysis of his system (engineering, accounting, purchasing, invoices, etc.).
2. **Secondary data**. This will be data obtained from third party sources, either through market analysis, estimates, databases, etc.

In the case of LCC, Standard EN 60300-3-3:2004 describes three basic methods for estimating the parameters of a cost element, cited just as an example (not necessarily corresponding to final methods used) [12]:

- Engineering costing method. Direct estimation of the cost attributes of particular cost elements by examining the product component by component or part by part. Often pre-established engineering cost drivers are used. For example, the labour costs of manufacturing a part would be estimated based on the production time of the part (person-hours) and the labour cost (€/person-hour).
- Analogy costing method. This is based on experience with similar products or technologies. Historical data is used, updated to reflect cost escalation, technological advances, etc. This technique is simple and less time-consuming. However, these reference costs can vary with market conditions, countries analysed, currency exchange rates, etc. and can therefore cause some uncertainty in the result.
- Parametric costing method. Uses parameters and variables to develop relationships for cost estimation, using equations that relate them. However, such equations are not always available for the different cost elements to be analysed. When performing an LCC, one or more of these methods may be used depending on the needs of the objective and scope of the study.

6.3. Impact assessment

In the case of the LCC, as only one Impact indicator (cost/benefit) is analysed, there are no Classification, Characterisation, Normalisation and Weighting stages, and this phase consists only of the aggregation of costs by cost categories, resulting from the Inventory phase [12].

In the case of LCC, the aggregation of costs is done using the Net Present Value (NPV) concept. The idea is to convert possible future costs to present value by considering a discount rate and, where appropriate, an escalation rate for certain flows that are expected to increase in price in the future. Basically, the aim is to estimate the present value of future costs [12].

Again, the process of allocating and relating the inventoried cost data to the impact categories is carried out in the matrix of the SimaPro LCA calculation tool. So, in the same way as for the environmental and social analysis, the tool will provide results in graphical format that will be interpreted afterwards.

6.4. Interpretation of results

In this last phase, the results provided by the SimaPro tool will be interpreted in the same way as the analysis of the environmental and social results. Specifically, the analysis of the cost results will pay special attention to identify the parameters that have more impact in each phase and in the LCC, considering those that may vary, in a more relevant way, according to [14]:

1. Price volatility of raw materials.
2. Market trends.
3. Legislative trends.

The following points are proposed:

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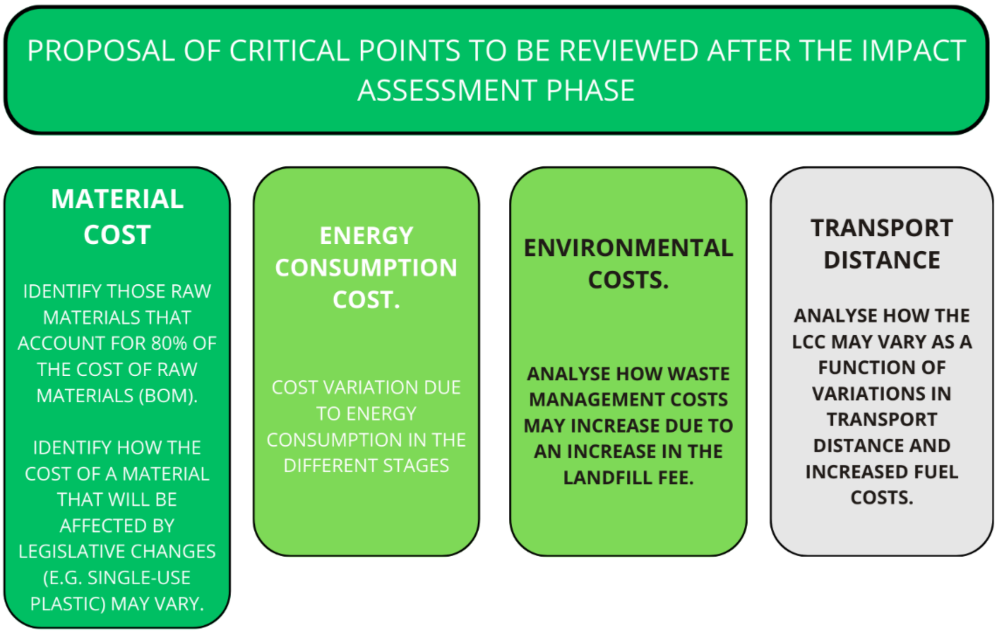

Figure 26: Critical points to be reviewed during the interpretation of results phase. Source ITE

6.4.1. Specific analyses of results

As indicated in the environmental LCA section, sensitivity and uncertainty analyses shall be carried out. The analysis of possible scenarios will lay the foundations for the mitigation plan and improvement proposals, as it will make it possible to assess how different variables behave in the face of the proposed changes and to choose between the measures with the greatest potential for improvement.

Within the evaluation of costs, given the characteristics of the denitrification process, it is foreseen that there may be a greater impact on the economic costs associated with the **machinery** involved in each phase, since it is a very innovative process and therefore with little or no room for manoeuvre to compare prices for the acquisition of machinery. For the same reason, a high level of qualification will be required from the **staff hired** for all phases of the project, so impacts associated with the performance of the work are also expected. Immediately afterwards, the costs associated with the **energy consumption** of the process will foreseeably be good candidates for study. Moreover, costs associated with **transportation** will be considered to the extent possible, taking into account that the acquisition of certain special equipment conditions the search for suppliers at an international level, as well as the limitations when quantifying said information.

7. Technical and functional energy monitoring and analysis

This section describes the general approach and procedure for energy monitoring and analysis. It is necessary to stress the importance of monitoring and analysing the energy consumption of any industrial process. The concept of energy efficiency underlies the intrinsic, deliberate, and reiterative improvement of industrial processes in the plant. Traditionally, there have been two trends in improving energy efficiency in manufacturing processes [15]; one focused on the introduction of new technologies for the improvement of process efficiency from a static and constant perspective (permanent improvements in the process), and the other focused on the improvement of the process operation through tools that allow a dynamic and constant analysis of the energy, operational and environmental efficiency of the process.

The project addresses the efficiency of its process from these two perspectives. In WP2 it is iterated on the basis of the results obtained in terms of reaction yields, effectiveness of water treatments, expected cycle times and other requirements. The objective of this WP is to obtain a functional prototype of the overall process that, in turn, meets the requirements of water quality, operability, energy efficiency, effectiveness and environmental sustainability. On the other hand, WP3 deals with the implementation of the pilots in each of the use cases, allowing to particularize the results of each of the stages and the process as a whole to the specificities of each type of water, water treatment plant, local climate, etc. While much of the performance tuning procedure is carried out during WP2 (specifically in the of design of every process stage and final plant design phases), it is expected that the most representative results of operational improvements of prototype tuning will be developed in WP3 with the final implementation of the pilots.

Moreover, energy efficiency analysis must consider conditions and variables directly or indirectly affecting energy performance of the plant, such as effective flow of treated water, generated Hydrogen, or sun hours of final location, to give some relevant examples. All these factors condition the energy feasibility of the plant because they depend on both the process and the context in which process is operated. It should also be considered that **LIFE ELEKTRA** has a demonstrative approach that should evaluate the adaptability of the pilot plant to other application contexts and scales, assessing its replicability and scalability.

As a result, the procedure for improving the energy efficiency of the process extends throughout the entire project, from the strategic decisions on the design of stages and integration between them, to the operations adjusted to the reality in which the activities are carried out. This leads to formulate a series of partial objectives to which the actions to improve energy efficiency in the plant should contribute:

1) Reduction of specific energy consumption (per cubic meter of treated water).
2) Reduction of operational energy consumption while guaranteeing the final quality of the product.
3) Maximizing energy self-sufficiency degree of the pilot plant as a whole.

Thus, the challenge of optimizing energy consumption is addressed in a cross-cutting manner, and it is at this point that the importance of data availability should be noted. As presented at the beginning of this document, three types of fundamental tools will be used, but all of them have the common requisite to present a significative amount of data relating both to the operation of the process as such, and to the context of exploitation. The availability of data is

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conditioned by the consolidation of progress in the pilot, which in turn depends on the results progressively achieved during the fine-tuning. The final design of the whole prototype is another critical point in which operational reference conditions must be defined, without prejudice to adaptations being made in each of the use cases due to the aforementioned implementation constraints. In any case, the final implementation will lead to a consolidation of the pilot to consider the scenario reached in the project. The following figure illustrates the different phases of the implementation of the methodology as described above:

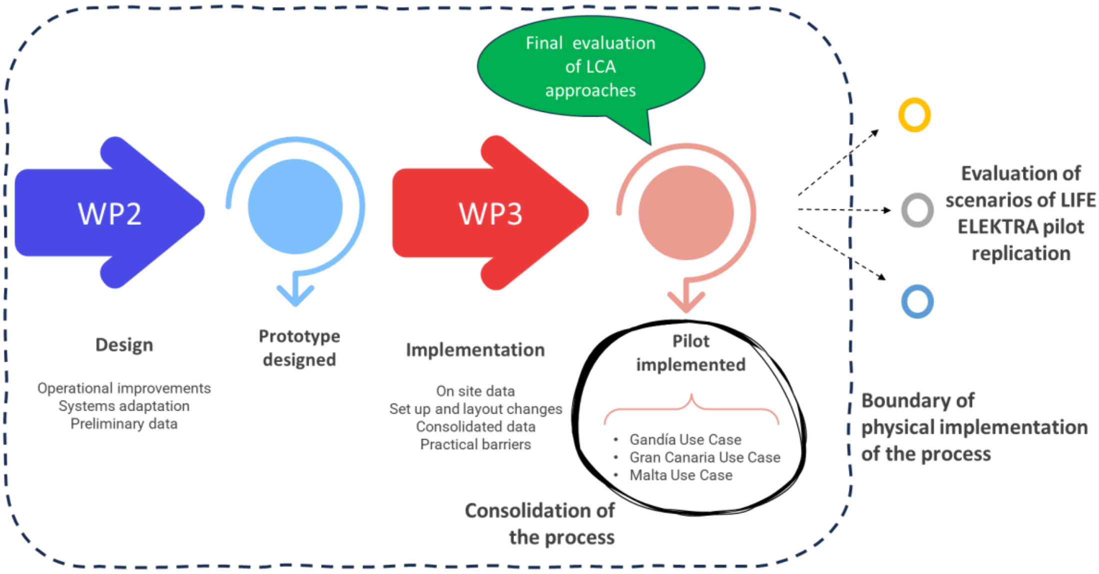

Figure 27. Phases of implementation of methodology in the context of technical monitoring and analysis. Source: ITE

7.1. Digital tools for analysis and optimization

In the context set out above, the usefulness of each envisaged tool is justified below in order to define the functionalities they must fulfil to achieve described objectives. **LIFE ELEKTRA** pilot considers the development and implementation of an Energy Management and Renewable Hybridization System (**EMRHS**), not only as a process management tool, but also as a data acquisition tool for data analysis to optimize process operations. Consequently, the design of the data acquisition functionalities of the system must be done considering:

- The final operation foreseen in the implemented process**. Aspects such as the degree of automation of each stage, the human and material resource requirements, or the effective cycle times are key aspects to consider. Similarly, the degree of continuous or discrete nature of the plant has a significant influence on the effective energy yield, as well as the productivity of the plant.**
- **The fundamental control and monitoring variables** according to the operational requirements of the process itself and/or indicators to be obtained from it.

There are different degrees of energy digitalization of a process. Each degree of digitalization is linked to deployment requirements and a corresponding degree of representativeness, with those levels of lower digitalization being much less representative but easier to implement, and the levels of higher digitalization being more complex in implementation but more representative. Each level also has a characteristic set of tools, methods, or procedures. The following figure schematizes this concept:

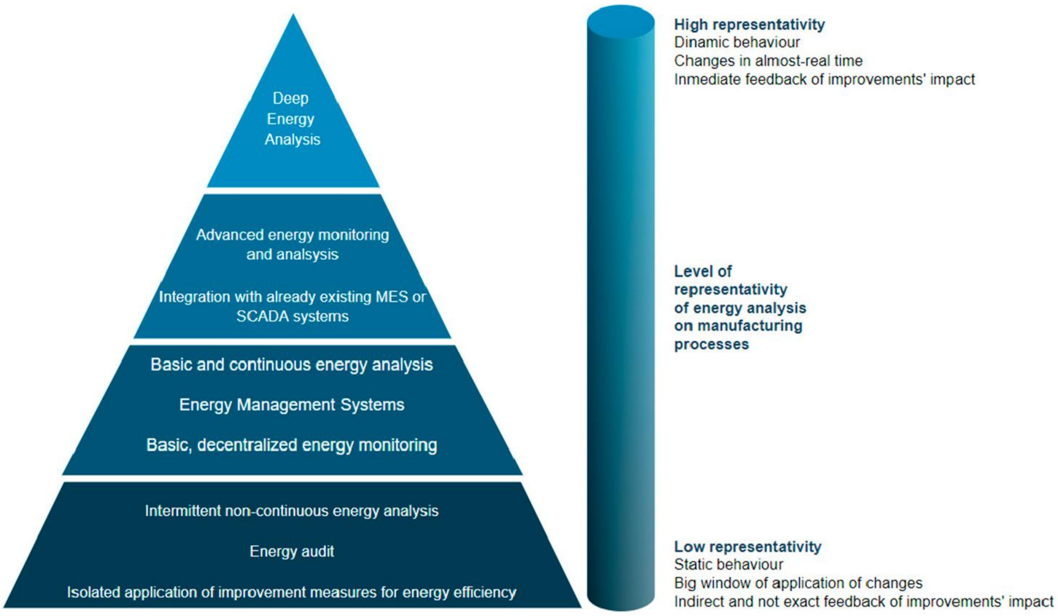

Figure 28. Different levels of representativity and commonly used tools for analysing and optimizing energy efficiency of the process. Source: ITE

The current and upcoming landscape of process operation, it is essential to reconsider the approach to enhance process energy efficiency while simultaneously adhering to production and quality benchmarks under an umbrella of sustainable operations in different dimensions. At this point, Digital Twin arises as a complex concept entailing a powerful approach to analyse both existing and non-existing scenarios. Operations, including equipment, human and material resources management, turns out to be the dimension most directly linked to the dynamic energy consumption of the industrial plant. In addition, there are a multitude of energy systems and ways of conceiving them, however all of them have a series of characteristics in common that must be evaluated:

Table 15: Identification and description of key aspects to be evaluated when selecting or designing a digital energy management system. Source: ITE

Key aspect	Description
DATA ACCESS CAPACITY	Ability of the system to not only record energy consumption data, but also to be able to access said data in a friendly and fast manner. E.g. with a filter and selection screen
METERING LEVEL	Quantity and type of meters distributed in the process. This metric evaluates whether important stages of the process are conveniently monitored or not
REPRESENTATIVENESS OF THE MEASURES	degree of detail provided by the company's energy monitoring, which can vary between obtaining daily, hourly, fifteen-minute consumption or even obtaining a detail of the process load curve at each time step
SYSTEM INTEGRATION WITH PRE-EXISTING SYSTEMS	Existence of other systems in the plant and degree of integration of energy data with the databases of said systems. For example, the existence of an MES provides a series of

	productive data that should be integrated with energy measurement and control systems.

Up to this point we have talked about measuring and exploiting existing data. This means that the system depends on the physical reality of the process, so that if it is intended to evaluate, for example, how the adjustment of the concentration and consequent variation of the cycle time impacts consumption, an adjustment experiment must be carried out that allows us to take the necessary data to draw those conclusions. However, there are cases in which situations are intended to be analysed which, either for reasons of profitability or simple physical feasibility, physical experiments or deliberate changes cannot be carried out. In these cases, the smartest approach is to recreate the physical process in a virtual environment on which to perform all the necessary tests and experiments at no more cost than computational cost and without risks.

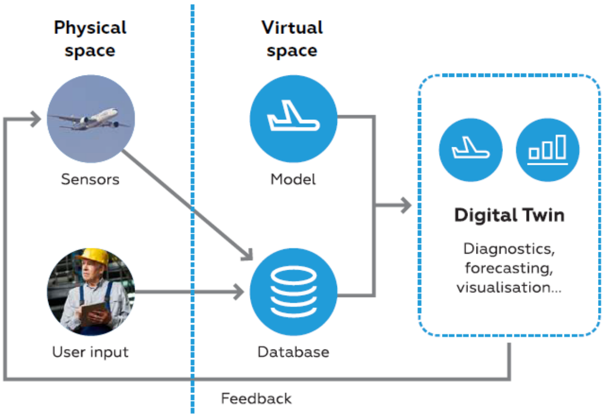

Figure 29: Concept of Digital Twin. Source: Anylogic [16]

This is the premise under which Digital Twins operate. In **LIFE ELEKTRA**, the use of the Digital Twin to be developed is twofold since the aim is both to optimize existing situations (through sufficient data exploitation to ensure the extraction of value from said data) and on the other to analyse scenarios that do not physically exist (still in the state in which they are simulated). As can be deduced, the development and operation of the Digital Twin in the project will be closely linked to the generation of data in the ERHMS.

7.2. Definition of simulation scenarios

At this point it makes sense to make a preliminary definition of the scenarios to be simulated, but it should be borne in mind that this definition can be adapted according to the requirements that are detected at the time of the simulations and according to the limitations in the modelling and data availability of the Digital Twin. Anyway, a clear differentiation is made between **two types of simulations**, distinguishing between existing scenarios and plant replication and scaling scenarios, which do not physically exist.

Already existing scenarios will be designed to analyse the impact of alternative operation of the process. No layout changes will be introduced in this kind of scenarios since the goal is to get information about current performance and ways to improve it. A preliminary list of key points Digital Twin should fulfil and calculate regarding this approach is provided, to be considered either separately or in a bundle of some of them:

- Energy balance for each step and for the whole process, in terms of kWh and kWh/m^3.
- Generation (kWh) and self-consumption balance (daily and yearly %) under variation of consumption and weather conditions as inputs.
- Mean power consumption of the process in the medium and long term.
- Effective flows (l/h if constant) in every significant point of the process.
- It may also be considered estimating general characteristics of purified water in terms of pH, conductivity or nitrates, but this will entirely depend on data available and its representativity, and also on degree of accuracy of calculation models developed.

This list is subject to be expanded with new requisites following the development and implementation of the solution and should be - and should be considered as a list of minimum requirements that must be met.

Replication and scaling up scenarios should provide a more decision-making support approach. As a consequence, the key points should be addressed to assess more strategic aspects such as:

- Operational cost of energy.
- Global consumption of the plant.
- Effective renewable generation and self-consumption degree.
- Effective inlet flowrate the pilot could admit.
- A way of evaluating, at least as a general approach, direct and indirect costs relating both CAPEX and OPEX.

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8. Process data generation and collection protocol

To conclude, some hints about data generation and collection is provided. A diversified list of data sources is considered:

- Energy Management System as main data source (for additional analysis) also acting as a data storage and control system.
- LCA approaches include general methods to collect information which could be provided by EMRHS (if related to short periods energy consumption of the pilot or process variables), by partners of the project or using public and built-in databases.
- Digital Twin scenarios are expected to generate simulated but still representative data following general guidelines provided in previous sections.
- Additional data sources and methods are still expected to be necessary.

The following figure exemplifies the approach to be followed and data generation related to project timeline implementation.

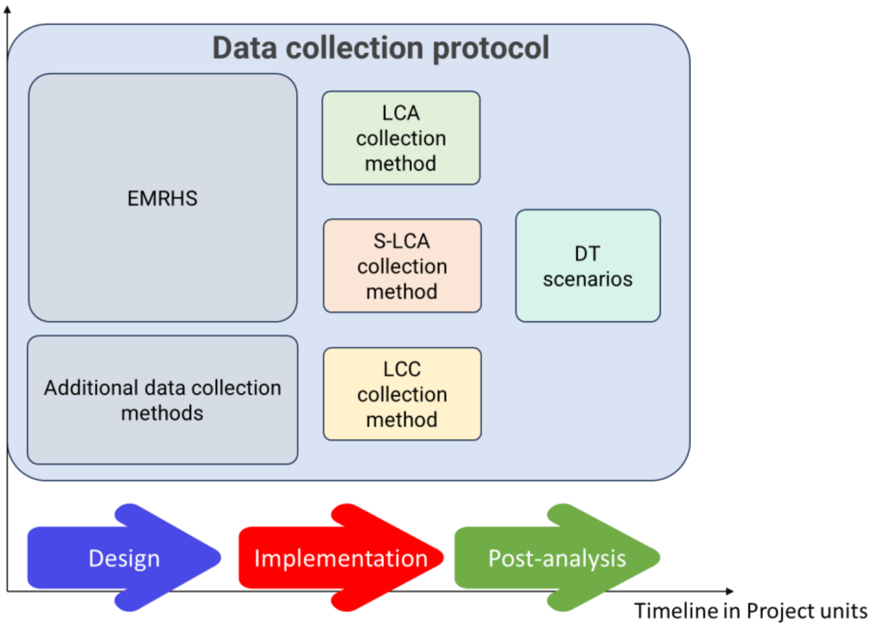

Figure 30: Data sources, methods and relationship with timeline of the project. Source: ITE

Anyway, a specific implementation of the protocol will be adapted to any partner following its availability, accessibility to the plant (Gandia use case is more accessible to Gran Canaria and Malta). This protocol will be consensual with the corresponding WP leader. Prior to conclude on an operative design of the plant, already available data will be collected and classified as a start point to work with LCA approach, which will be adjusted to process changes and end conditions, as described previously. A summary of sources of information is listed below:

- Questionnaire data (As main tool to collect information from partners and stakeholders).
- Data obtained from the EMRHS.
- Bibliography, technical information obtained from manufacturers (Technical brochures, etc.).

9. Conclusions

The deliverable has justified the importance and necessity of developing and applying a circular impact analysis methodology given the needs of the project. For this purpose, the different tools, methods and procedures to be applied have been described, defining general guidelines that are expected to meet the application cases, and making a forecast of the methodology implementation approach to meet the required objectives.

One of the key aspects in implementing the methodology will be the availability and accessibility of data, which in the case of LCA analysis represents the bulk of the work in the development of inventories. For these, sources of information that are expected to be available and general protocols for data collection have been defined. On the other hand, the EMRHS will be designed and implemented considering data needs and the deployment constraints of the solution, so that the needs are aligned. In any case, a particular collection protocol will be defined with each WP leader due to the particularities of each pilot.

All those data that cannot be obtained, as well as use cases that cannot be physically addressed, will be studied by means of the Digital Twin, which completes the triad of tools to be deployed and will provide a vision of the replicability of the plant in contexts not directly addressed in the project.

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