



Preliminary and Summary of LCA's

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HURRICANE

Month 12



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Project Summary

Within HURRICANE a sector-coupling circular hub centered around the ArcelorMittal Ghent site will be created. We will target efficient resource management together with the recovery and utilization of squandered industrial waste heat and water. Together with ArcelorMittal Ghent's ongoing initiatives, this will lead to a reduction of energy, water and raw materials by at least 20%. Thanks to the ongoing projects taking place within and around the Ghent site, the site is already well connected to many other industries like waste suppliers, chemical producers (ethanol offtake & H₂ waste gas), renewable power producers, and wastewater treatment. It has become a multi-sectoral hub leading to efficient implementation of industrial symbiosis concepts. The Ghent site has a significant amount of recyclable energy, material and water that allows this symbiosis. These aspects are not only from the steel making processes, but also from other operations taking place in the mentioned "multi-sectoral" hub. This hub can be further enhanced with the integration of waste heat with its ongoing initiatives. Our solution aims at developing and demonstrating novel heat recovery (heat exchanger) and upgrading (heat pumps) solutions from selected operations and then coupling it with the internal and external off takers by means of a heat grid. With digital tools, aspects like broadening the district heating network, and adapting the heat demand profile of the buildings to better match the intermittent of the waste heat, can be optimized. Finally, an integrated software tool for circular hubs that combines the different tools and data produced at the different operations will be developed and validated. Through two virtual demonstrations and circular hubs blueprint the replication potential will be proven. The consortium is formed by 11 partners from 5 different countries, including 4 research organizations, 1 large End User, 2 SMEs, 3 civil organizations and 1 linked 3rd party.

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Executive Summary

This deliverable focuses on the description of the Life Cycle Assessment (LCA) tool that will be used for analyzing the environmental impact of the Hurricane project. Within HURRICANE project a circular hub will be created. Moreover, different kinds of heat recovery technologies will be implemented to recover the waste heat from the different operations within ArcelorMittal Ghent plant. This waste heat recovered will be used to feed a district heating network that will be able to heat not only ArcelorMittal buildings but also external buildings, such as for example in the municipality of Zelzate. This will lead to a reduction of energy, water, raw materials and GHG emissions.

The LCA will follow ISO 14040:2006 and ISO 14044:2006 standards, with modelling carried out using SIMAPRO software. In addition, the Goal and Scope Definition phase results are presented as first-year targets, while further LCA phases results will be covered in Milestone 5.2.

Key Results:

- **Literature review:** significant progress has been made in the recovery of waste heat from various sources in the steel industry, but further research is needed to explore the potential for combining waste heat recovery with district heating systems,
- **Goal and Scope definition:** Assessing the environmental impact of recovering waste heat from different operations that occur in the steelmaking plant to reduce the use of natural gas and other fossil fuel, water and energy.
- **Reference flow:** 1 MWh of thermal energy used for heating internal and external buildings.
- **Impact categories:** Selection of 14 impact categories in accordance with ReCiPe 2016 Midpoint (H) method.
- **Definition of System boundaries:**
 - o **Current situation:** Waste heat is not recovered; heating is powered by natural gas in the case of external off-takers, and by either light fuel or steam for ArcelorMittal Belgium.
 - o **Future situation:** Waste heat will be recovered and used for district heating, including the implementation of heat pumps and necessary infrastructure.

1 Introduction

The introduction is divided into two sections. Section 1.1 defines the scope of this deliverable and provides a timeline for the LCA activity, while Section 1.2 outlines the structure of the deliverable.

1.1 Scope of this deliverable

The scope of this deliverable is to provide an overview of the LCA tool, including its principles, origins, reference standards, and the phases necessary to conduct this analysis, with a description provided for each phase.

Specifically, a timeline of the key phases of the LCA process within the Hurricane project, is provided in Figure 1, with activities planned according to the project years as follows:

- **First year:** Goal and Scope Definition (Dark Red)
- **Second and third year:** Life Cycle Inventory (Yellow)
- **Fourth year:** Life Cycle Impact Assessment (Light Blue)
- **Fifth year:** Results and Interpretation (Green)

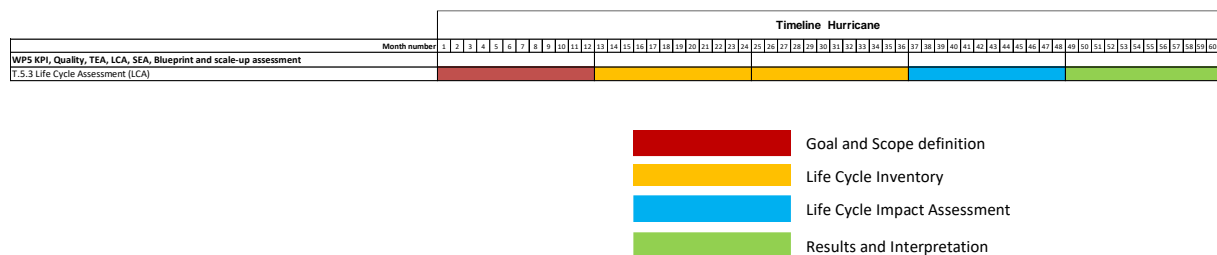


Figure 1 - Timeline of LCA Phases in the Hurricane Project

Additionally, this report presents the first results achieved so far for the LCA conducted for the Hurricane project. Only the Goal and Scope Definition phase results are included, as this phase represents the first-year target, according to the timeline outlined in Figure 1.

Results from the other LCA phases will be reported in Milestone 5.2: LCA and TEA studies, due in month 58.

1.2 Outline of this deliverable

This deliverable is structured to first provide an overview of the LCA tool, including its history, reference standards, and key principles, and then to explain in detail each phase required by the standard to conduct the analysis. Additionally, the report will present the results achieved so far in the LCA analysis for the Hurricane project. Specifically, the chapters are structured as follows:

- **Chapter 2** provides a concise summary of the LCA tool, its history, and the relevant ISO standards.
- **Chapter 3** focuses on the first phase of LCA, presenting the methodology, followed by the results achieved during the first year of the Hurricane project for this phase.
- **Chapters 4, 5, and 6** are dedicated to the methodology for the Life Cycle Inventory, Life Cycle Impact Assessment, and Result and Interpretation phases, respectively.

2 Life Cycle Assessment

LCA is a tool where Life Cycle Thinking is applied. This is a decision making tool that allows to analyze environmental, social and economic impacts during the entire life cycle of a product, service or process in order to reduce and optimize resources consumption, reduce polluting emissions and improve socioeconomic performance of the product. With the Life Cycle Thinking it is possible to relate social, economic and environmental dimensions.

Life Cycle Thinking is applied in Life Cycle Costing (LCC), in Social Life Cycle Assessment (S-LCA) and in Environmental Life Cycle Assessment (E-LCA).

Life Cycle Costing is a technique that assesses costs over the life cycle of a product or service.

Social Life Cycle Assessment is focused on aspects that might impact stakeholders throughout the entire product, service or process' life cycle.

Environmental Life Cycle Assessment, instead, allows to assess potential environmental impacts and resources used throughout a life cycle of a product, service or process, from raw material acquisition, via production and use stages, to waste management.

2.1 LCA History

Concern over environmental pollution and energy and material scarcity have led to the development of Life cycle-oriented approaches, which have been developed since the 1960s, thanks to the collaboration between universities and industries, in the USA first and then in Northern Europe.

Early methods were focused on inventorying energy and resource use, emissions and generation of solid waste, from each industrial process in the life cycle of a product system. After that period, as inventory got more complex, attention was extended to potential environmental impacts.

In the 1990s, different methods were developed, with the aim of assessing environmental impacts. The first one was CML92 that was released in 1992 by Institute of Environmental Sciences in the Netherlands. In 1999 Eco-Indicator 99 methodology was released with a more science-based approach. During the same years a number of life cycle inventory databases were released by different organizations covering different industry sectors. But, due to differences between standards and data quality, the resource uses and emissions of a single industrial process could differ in the different databases. For this reason, in 2003, the first Ecoinvent database was released and it covered all industrial sectors and aimed for consistent data standard and quality.

Always in 1990s, the modelling of increasingly complex product system and the proliferation of LCI data and impact assessment methodology created the need for dedicated LCA software. Indeed, the first versions of SimaPro and GaBi were launched.

2.2 ISO standard

Since the 1990s SETAC (Society of Environmental Toxicology and Chemistry) organized a workshop series that culminated in 1993 with the first official guidelines for LCA: Code of Practice for LCA. Thanks to their success, in 1993 a formal standardization process was initiated by the International Organization of Standardization (ISO) to develop a global standard for LCA. This process led to the adoption and release of four standards:

- ISO 14040: principles and frameworks
- ISO 14041: Goal and Scope definition
- ISO 14042: Life Cycle Impact Assessment
- ISO 14043: Life Cycle Interpretation.

In 2006 these standards have been reviewed and in this revision ISO 14041, ISO 14042 and ISO 14043 were grouped into the ISO 14044 standard.

2.3 LCA phases

ISO 14040 identifies the following phases needed to carry out a LCA analysis (Figure 2):

- Goal and Scope definition
- Life Cycle Inventory
- Life Cycle Impact Assessment
- Interpretation and Results

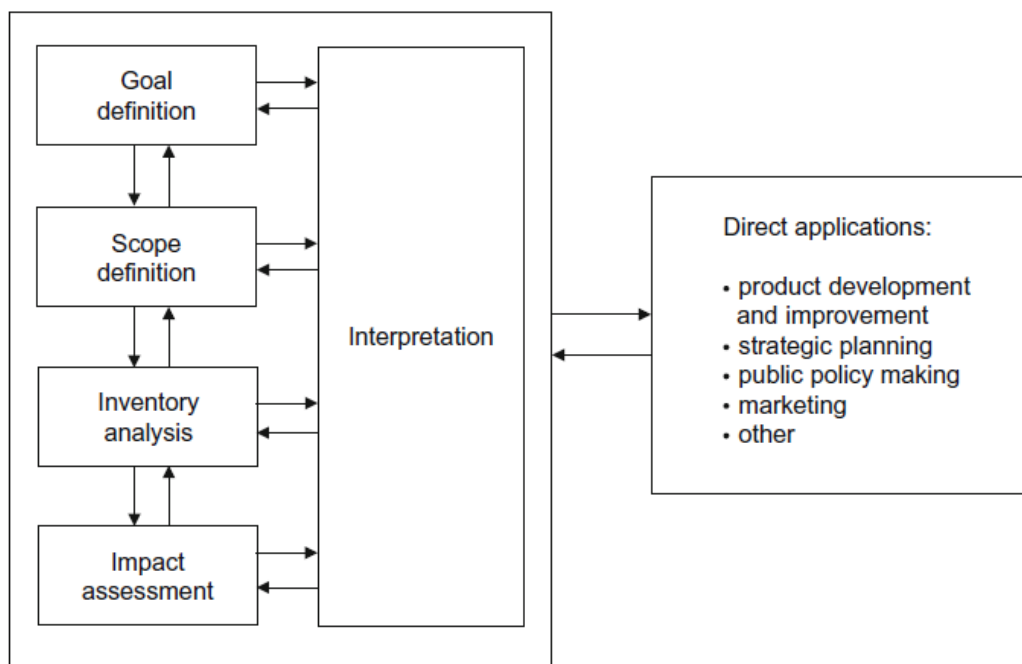


Figure 2 – LCA's phases

3 Goal and Scope definition

This chapter is divided into three sections. Specifically, Section 3.1 provides a literature review on waste heat recovery in the steel industry, Section 3.2 outlines the methodology, and Section 3.2 describes the results of the Goal and Scope definition phase.

3.1 Literature Review

The recovery of waste heat in the steel industry has gained significant attention due to its potential to improve energy efficiency, reduce CO₂ emissions, and contribute to sustainable production. Various methods have been explored in recent years to recover and utilize surplus heat generated during steelmaking processes. These include heat recovery from slag, exhaust gases from Electric Arc Furnaces (EAF) and Basic Oxygen Furnaces (BOF), as well as heat from rolling reheating furnaces.

Ma et al., (2012) analyzed the state of waste heat recovery and utilization in China's steel industry. The sources of this waste heat were diverse, including the ironmaking process, sintering, coking, slag, cooling water, and more. The study highlighted significant challenges in recovering and using this heat due to variations in quantity, quality, and type. Specifically, waste heat is categorized into three grades: high, medium, and low. For each category, the recovery rates were reported to be low, underscoring the need for targeted technologies tailored to each stage of steel production to enhance efficiency.

Similarly, Zhang et al., (2013) conducted a comprehensive review of heat recovery technologies, with a particular focus on recovering heat from molten slag. The review explored both physical and chemical methods. Physical methods recover waste heat to generate energy, preheat blast furnace flue gas, and produce steam, with some approaches enabling direct conversion of waste heat into thermoelectric energy. In contrast, chemical methods transfer the recovered waste heat into chemical energy. This study underscored the significant potential of molten slag as a heat source but also noted that the technology for efficient recovery remains underdeveloped in many facilities.

More recently, Inayat (2023) proposed an overview on the current progress of waste heat recovery systems and their integration in the steel and iron industry.

A significant gap in the literature is the limited application of waste heat recovery systems for district heating, particularly in the steel industry. In fact, it is common to find articles about the storage of waste heat (Zamengo et al., 2015; Ortega-Fernández & Rodríguez-Aseguinolaza, 2019) and the use of different systems that allow to recover waste heat and then convert it into electricity, like thermoelectric generation system (TEG) (Kuroki et al., 2015) or Organic ranking Cycle (ORC) system. For example, regarding the latest, Campana et al. (2013) examined its potential to recover heat from exhaust gases in European energy-intensive industries, including steel productions. Their results suggested that the ORC system could effectively recover heat from the EAF gas and reheating furnaces, contributing to significant energy savings and CO₂ emissions reductions. Likewise, Kaška (2014) investigated the use of ORC system to generate electricity from excess heat coming from walking beam slab furnace which is extracted by water used to cool the walking beam skids.

Also, a more recent study by Alshehhi et al. (2023) analysed the ORC system in two distinct scenarios to recover waste heat from EAF gas: one using an Oil Loop with ORC and the other incorporating Thermal Energy Storage with ORC. The study demonstrated that in the first scenario approximately 24% of off-gas heat could be recovered from the EAF, while in the second scenario a recovery rate of 27% could be achieved.

Additionally, several studies have performed Life Cycle Assessments (LCAs) to evaluate the environmental impact of recovering waste heat using ORC systems (Liu et al., 2013; Pili et al., 2020).

Regarding the application of waste heat recovery system to feed district heating network, Di Santo et al. (2014) considered two waste heat sources: exhaust gases from the reheating furnace and exhaust gases from the EAF. The study evaluated four scenarios among which the district heating is included. Exhaust gases from EAF are considered as waste heat source to recover and use in district heating network, especially during winter period, also in another article of 2017 (Ramirez et al., 2017)

Li et al. (2016) conducted a study focusing on recovering industrial surplus heat for district heating in Northern China. Their system utilized three main sources of waste heat: slag flushing water from blast furnaces, cooling water, and mixed saturated steam from BOF and rolling heating furnaces. The study employed advanced technologies, including heat exchangers, absorption heat pumps, and absorption temperature transformers (ATTs) to efficiently recover that waste heat for district heating.

Of these studies, the work by Li et al. (2016) bears the closest resemblance to the Hurricane project, as it used heat exchangers and heat pumps to recover waste heat for district heating. However, the Hurricane project goes further by investigating a wider range of heat sources, including, but not limited to the walking beam furnace and coils from the hot strip mill. Moreover, Hurricane will investigate innovative processes such as Torero, Steelanol, and RecHycle, considering them as additional waste heat sources.

In summary, while significant progress has been made in recovering waste heat from various sources in the steel industry, a notable gap remains in integrating these technologies for broader applications, such as district heating. Most waste heat recovery efforts focused on electricity generation through ORC systems, with comparatively little emphasis on utilizing waste heat for heating purposes, as seen in projects like Hurricane. Further research is essential to fully explore the potential of combining waste heat recovery with district heating systems, especially to meet heating demands during the winter season.

3.2 Methodology

A LCA study starts with the definition of the goal of the study that allows to set the context of the LCA study and is the basis of the scope definition.

In the goal definition the aim is to answer to the questions like “Why is the study conducted?” and “Which questions is it intended to answer and for whom is it performed?”. Hence, in this phase it is defined:

- **Intended application of the study.** LCA analysis can be used to compare environmental impacts of particular products or services, to identify the parts of a product system that contribute the most to its environmental impact, to evaluate potential improvements from changes in product design, to document the environmental performance of products, to develop criteria for an eco-label or to develop policies that considers environmental aspects;
- **Limitations due to methodological choices** that can concern impact categories taken into consideration, or if one or more of life cycle's phases were not considered and how this could affect the results;
- **Reasons for carrying out the study;**

- **Target audience** that influences the level of detail of the study and the technical level of communication and results interpretation;
- **Commissioner of the study and other kind of influential actors**
- **If the study will be disclosed to the public.**

Once the goal is defined, the next step is to define the scope of the study, which determines what product system is to be assessed and how this assessment should take place. In this phase it is defined:

- **The object of the assessment** which is represented by functional unit that defines qualitative and quantitative aspects of the function. Once the function and the functional unit have been defined it is necessary to set the reference flow, i.e. product quantity needed to obtain the functional unit and that represents the starting point for inventory analysis;
- **Life cycle inventory modelling framework** (attributorial or consequential) and how multifunctional processes should be managed;

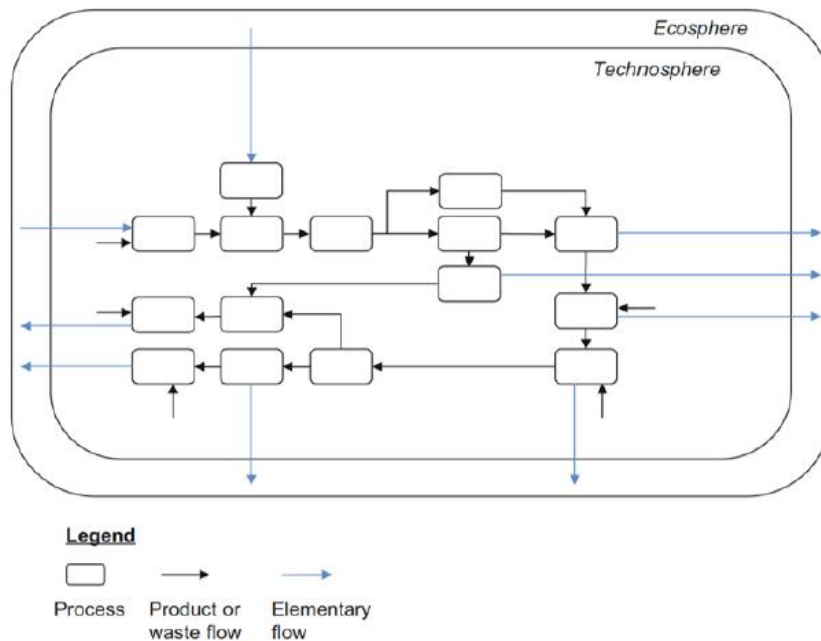


Figure 3 - Representation of System Boundaries

- **System boundaries and completeness requirements.** System boundaries set boundaries between the product system defined, Technosphere and ecosphere (Figure 3). Within the system boundaries should be included all unit processes needed to provide the reference flow. The completeness requirements allow to determine which processes should be included within the system boundaries to reach needed level of completeness in accordance with the goal.
- **Representativeness of LCI data.** Unit processes must be representative of real processes that are actually used in the product system assessed. The representativeness can be geographical, time-related and technological.

- **Preparing the basis for the impact assessment.** This includes impact categories and LCIA method choice.

3.3 Results

The aim of the study has been set by taking into account both main aims of Hurricane project reported into the Proposal, i.e. development of technologies that are able to recover waste heat from different operations which occur within the plant and the use of this recovered heat for heating internal buildings, like ArcelorMittal Belgium buildings, and external buildings, such as Psychiatric centrum at SJB and municipality of Zelzate, and the state-of-art, where many district heating system are currently dependent on natural gas and waste heat generated from industrial processes can be recovered reducing the need of natural gas.

In accordance with this, the LCA goal is to verify and quantify the GHG emissions reduction and the potential savings in resources consumption (water, fossil fuel, energy). To do this, it is necessary to analyze both the current and the future situation and compare them. In the current situation waste heat is not recovered and the heat production system is fed with natural gas, in the case of external off-takers, and with either light fuel or steam for ArcelorMittal Belgium. Instead, in the future situation the waste heat will be recovered and used to feed a district heating system.

The reference flow selected is 1 MWh of thermal energy used for heating both internal and external buildings. Currently, this thermal energy is supplied by natural gas and other fossil fuels. In the future, however, it will be sourced from waste heat recovered from various processes within the plant, as well as from ongoing projects aimed at optimizing energy recovery.

Regarding the impact categories, the initial approach was to use the same categories presented in a 2010 article on the ArcelorMittal Gent plant (Van Caneghem et al., 2010) However, it was later decided to adopt the impact categories from the ReCiPe Midpoint (H) method, as the categories used in the article were derived from a combination of two methods that are now considered outdated. So, the selected impacts categories are:

- Global warming;
- Ozone depletion;
- Human toxicity cancer effect;
- Human toxicity non-cancer effect;
- Particulate matter;
- Ionizing radiation;
- Photochemical ozone formation;
- Acidification;
- Terrestrial eutrophication;
- Freshwater and Marine eutrophication;
- Freshwater eco-toxicity;
- Land use;

- Water resource depletion;
- Mineral fossil and renewable depletion.

On system boundaries, as the study will compare current situation with future situation, there will be two situations to analyze:

- **Current situation** (Figure 4) where waste heat that comes from different operations that occur in Ghent plant, i.e. walking beam furnace, coils of the hot strip mill, tunnel and cooling bath, is not recovered and internal and external buildings are fed by natural gas, in the case of external off-takers, and by either light fuel or steam for ArcelorMittal Belgium.

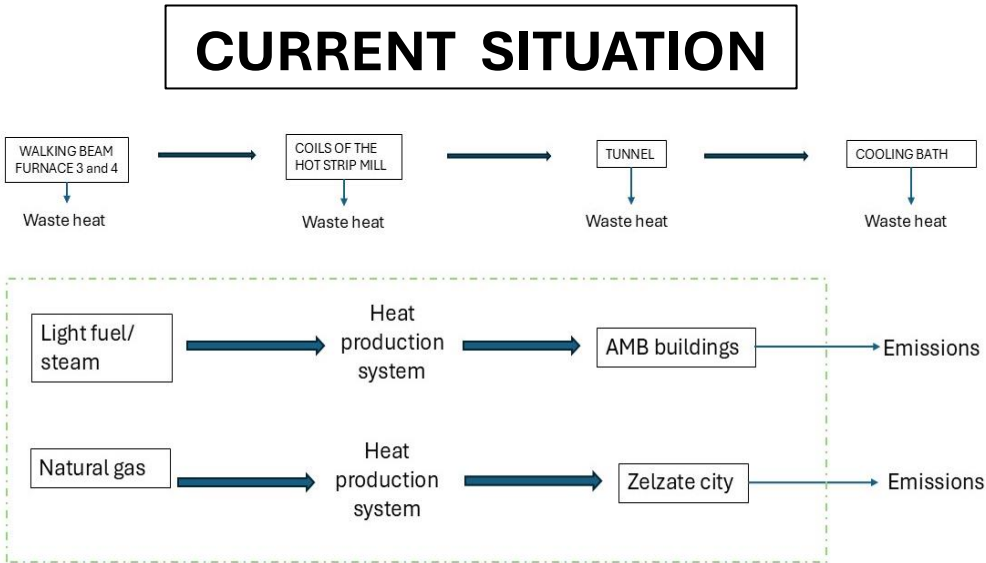


Figure 4 - System Boundaries of current situation

- **Future situation** (Figure 5) where waste heat coming from operations that occur within the plant is recovered through different type of heat exchangers. The recovered heat will be transported into an energy central and then into a district heating network in order to provide heat to internal and external users. A heat pump will be needed to allow heating into the halls of the cold strip mill. Heat recovering from other ongoing projects, like Steelanol, Torero and Rechycle, will be eventually studied/simulated (represented in green in Figure 5). In this situation, system boundaries also include the manufacturing of heat exchangers, heat pump, steam turbine and pipeline, which will be built with the aim to link the Ghent plant to the municipality of Zelzate.

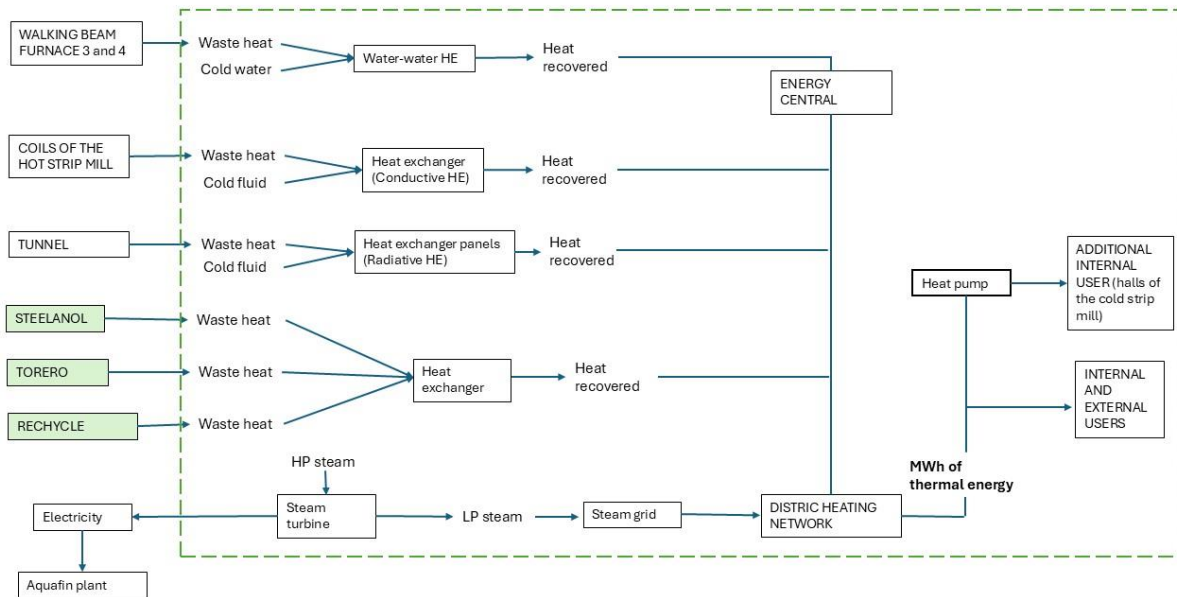


Figure 5 - System Boundaries of future situation

4 Life Cycle Inventory

Inventory analysis represents the LCA phase where all information about physical flows both in terms of inputs of resources, materials, semi products, byproducts, products and outputs of emissions, products and valuable products for product system are collected in accordance with Goal and Scope Definition phase. In this phase all processes included in the product system are taken into account and flows are related to the reference flow which is determined by functional unit.

Data collection needs to be planned. First of all, it is important to identify processes of the product system in order to have a detailed representation of background and foreground system.

Then data can be collected. Data can be considered as primary data or secondary data. The first ones are specific data provided by study commissioner, while the second ones are collected using LCI databases (i.e. Ecoinvent, ELCD, USLCL,..) or from literature.

Once data has been collected, unit process construction is the next step needed to build LCI model by using LCA software, like SimaPro, GaBi, OpenLCA.

LCI result is a list of quantified elementary flows that cross system boundaries of life cycle assessed, and it is used like input in the Life Cycle Assessment phase.

5 Life Cycle Impact Assessment

In the Life Cycle Impact Assessment phase information coming from Life Cycle Inventory phase is translated into environmental impacts.

The aim is to examine the product system from an environmental point of view by using impact categories and categories indicators together with LCI results.

This led to information useful for interpretation phase.

ISO 14040/140444 indicates five steps to conduct this phase. Three of these steps are mandatory, while two of them are optional. Mandatory steps are:

- **Selection of impact categories**, category indicators and characterization models
- **Classification** that means assigning LCI results to impact categories according to their potential effects.
- **Characterization**, i.e. quantifying the ability of every elementary flow to impact on particular impact category.

Instead, the optional steps are:

- **Normalization**, relating different potential impacts with a common scale in order to express them using a common unit and provide an overview of which environmental impacts are higher and which of them are lower in accordance with the reference system.
- **Weighting** consists of applying weight on every category indicator to support comparison between impact categories and obtaining a total environmental impact score for the product system.

6 Results and Interpretation

In the result and interpretation phase results of the study are interpreted to answer questions defined during the Goal and Scope Definition phase. During the interpretation it is important to consider not only the goal and the scope but also the suitability of functional unit and system boundaries.

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