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Author(s)

	Partner name	Name of the author
Main Author	Quantis	Anna Kounina Arnaud Dauriat
Co-authors	N-Side	Héloïse Hoyos François Raucent
	AMMR	Hervé Lavelaine Mauro Chiappini
	EDF	Morgan Barberousse Caroline Bono Anne Debregeas Dominique Daniel

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Glossary

BF-BOF	Blast furnace – basic oxygen furnace
CAPEX	Capital Expenditure
CFC	Chlorofluorocarbon
CTUe	Cumulative Toxic Unit from ecosystems
CTUh	Cumulative Toxic Unit from humans
DRI	Direct Reduced Iron
DSR	Demand Side Response
EAF	Electric Arc Furnace
EF	Environmental Footprint
ENTSO-E	European Network of Transmission System Operators for Electricity
FU	Functional unit
GHG	Greenhouse gases
HRC	Hot rolled coil(s)
IERO	Iron production by Electrochemical Reduction of its Oxide for high CO_2 mitigation
ISO	International Organization for Standardization
IT	Information Technology
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LMC	Levelised manufacturing cost
MJ	Megajoule
NPV	Net Present Value
O&M	Operation and Maintenance
PEF	Product Environmental Footprint
PM2.5	Particulate Matter 2.5 μm
RES	Renewable Energy Sources
ROI	Return on Investment
RTE	Réseau de Transport d'Electricité (the French electricity network operator)
SMGP	Single Market for Green Products
TYNDP	ENTSO-E 10-year network development plan

1 Executive summary

D7.1 is the first deliverable of WP7 that ensures a common basis for the evaluation of the investigated technology, including the goal and scope of the environmental LCA and LCC (functional unit(s), system(s) to be studied, system boundaries, time horizon for the assessment of the investigated technology per system, most relevant indicators and life cycle impact assessment methods to be applied, specific application(s) of the system, reference technologies to which the novel technologies shall be compared) as well as the data collection management plan to ensure good quality input data for these different studies.

For instance, the "**functional unit**" that serves as an anchor point of the comparison between two products ensuring that the compared alternatives do indeed fulfil the same function has been defined as 1) the production of 1 t of mild steel (steel grade is not relevant) as hot rolled coil (reference product that corresponds to rolls laminated at 900°C) and 2) the European total production (the ULCOWIN technology penetration will depend on the European Commission climate agenda). A focus can also be performed on specific countries with regional electricity mix modelling. The **studied system** has been defined as cradle-to-gate steel production, gate referring to hot rolled coil. The main **reference technology** to benchmark the ULCOWIN technology performance is blast furnace (BF), followed by Basic Oxygen Furnace (BOF). The techno-economic and environmental studies will assess both the current steel production as well as future **time horizons** for which steel production with conventional technologies or the ULCOWIN technology will be assessed. The 2030 and 2050 models will be compared with the 2030 scenario with the European Commission emission targets for 2030 as well as the 2050 European low-carbon economy roadmap.

The management of data collection (including coordination among partners, preparation of data collection templates, overall time plan, etc.) is addressed as part of the framework definition. Data collection is indeed a crucial part of the techno-economic and environmental assessment. The required data has been split in several categories, i.e. technology-related data, energy market data, raw materials and by-product market data, environmental costs and restrictions as well as miscellaneous data, the European energy system data, and steel industry data. The **technology-related data** category includes all information and data related to materials and energy efficiencies, as well as the equipment costs, operations and maintenance costs. It includes for instance raw materials input (iron ore, scrap, limestone, oxygen, etc), fossil fuel input (natural gas, coal, coke, diesel), electricity input, by-product output (oxygen, slag, scrap, etc) and possible waste disposal costs and polluting gas emissions (CO_2, CO, SO_x, NO_x). The **energy market data** include electricity prices, natural gas prices, coal (and possibly coke) market prices. **Raw materials and by-product market data** include iron ore prices, scrap buying price, price of ferroalloys, price of limestone, slag reselling price and scrap reselling price. **European energy system data** include electricity mix, grid connexions, consumption profile, demand response capacities and climate fluctuations. **Steel industry data** include the European primary steel production figures, in each European country, and the sector evolution. Finally, a few key variables should be quantified to integrate **environmental costs and restrictions**. These data include CO_2 emission allowances, CO_2 equivalent factors for other polluting gases (if applicable), restriction on maximum allowed emission levels (if applicable, e.g. for SO_x and NO_x), acquisition and assembly cost of gas treatment technologies (e.g. for SO_x and NO_x), operation and maintenance costs of gas treatment technologies. In addition to the previously listed data, the analysis also requires some general parameters to be quantified, for example the ULCOWIN facility lifetime that needs to be estimated.

In a nutshell, deliverable D7.1 defines the scope for each study (techno-economic, environmental, and process integration with RES), the expected deliverables of each task, the working methods, the input data in several categories, and the connexion between the different studies. A special attention is paid in the report on the common input data between all partners, in order to ensuring consistency between the economic, environmental and energy scenarios.

2 Introduction

The European Commission has set itself a long-term goal of reducing greenhouse gas emissions by 80-95% in Europe, when compared to 1990 levels, by 2050. In order to achieve this objective, several scenarios of energy, transport and GHG emissions have been studied. A key conclusion is that decarbonising the energy system is technically and economically feasible. However, to achieve this goal, significant investments need to be made in new low-carbon technologies, renewable energy, energy efficiency, and grid infrastructure.

The ΣIDERWIN project should support Europe to achieve these targets. In WP7, key objectives are to:

- Assess how the ULCOWIN process can contribute to the Renewable Energy Sources (RES) integration in Europe
- Perform a techno-economic study of the process through the establishment of economical scenarios of the electricity demand resulting from the development of electricity-based steel production processes
- Evaluate the life cycle environmental and cost performance of the investigated process by means of environmental life cycle assessment (LCA) and life cycle costing (LCC)
- Guide the design and development of the investigated electrochemical process towards more sustainable solutions.

D7.1 is the first deliverable of WP7 and aims at defining the framework of the techno-economic and environmental assessment and ensure a common basis for the evaluation of the investigated technology, including the goal and scope of the environmental LCA and LCC (functional unit(s), system(s) to be studied, system boundaries, time horizon for the assessment of the investigated technology per system, most relevant indicators and life cycle impact assessment methods to be applied, specific application(s) of the system, reference technologies to which the novel technologies shall be compared) as well as the data collection management plan to ensure good quality input data for these different studies.

This framework will serve as a basis to ensure a common understanding from all the partners of the work to be performed throughout WP7.

The management of data collection (including coordination among partners, preparation of data collection templates, overall time plan, etc.) is addressed as part of the framework definition. Data collection is indeed a crucial part of the technoeconomic and environmental assessment. The key to a good and reliable assessment is the availability of robust and reliable data.

3 Framework of the techno-economic and environmental assessment

3.1 Functional unit

Life cycle assessment and life cycle cost analysis rely on a "functional unit" (FU) for comparison of alternative products that may substitute each other in fulfilling a certain function for the user or consumer. The FU describes this function in quantitative terms and serves as an anchor point of the comparison ensuring that the compared alternatives do indeed fulfil the same function. It is therefore critical that this parameter is clearly defined and measurable.

In this study, two different functional units have been defined to provide different interpretation angles:

- The production of 1 t of mild steel (steel grade is not relevant) as hot rolled coil (reference product that corresponds to rolls laminated at 900°C).
- The European total production (the ULCOWIN technology penetration will depend on the European Commission climate agenda). The uptake of the technology at large scale is expected for 2040-2050, while first plants could function in 2020-2030. The functional unit can be defined at the European scale, while a focus can be performed on specific countries with regional electricity mix modelling

a.

b.

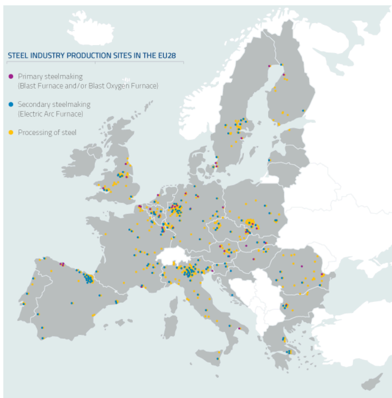

Figure 3.1: a. Steel hot rolled coil, b. European steel productions sites

3.2 Studied system

The system boundaries identify the life cycle stages, processes, and flows considered in the analysis and should include all activities relevant to attaining the study objectives.

Until M36, the techno-economical and environmental studies will focus on cradle-to-gate steel production, gate referring to hot rolled coil.

After M36, a cradle-to-grave study will be carried that include use stage and steel recycling (recycling may be key to evaluate the environmental impact, but not the focus of this project).

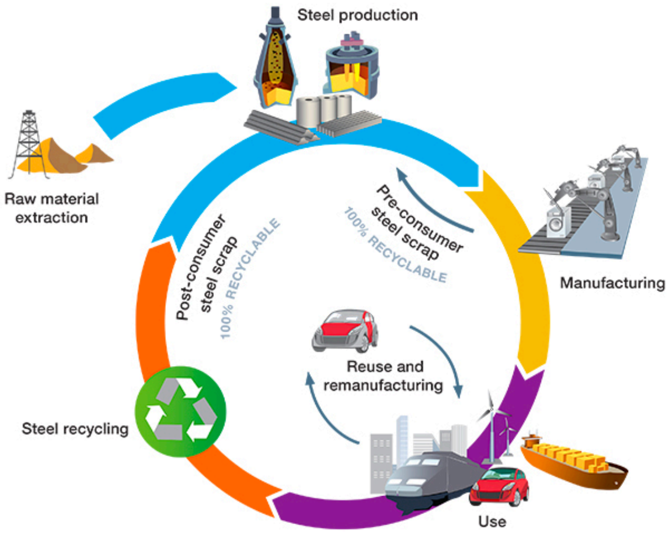

Figure 3.2: Cradle-to-grave life cycle system for steel, from Worldsteel 2015 Steel in the circular economy, a life cycle perspective

3.3 Reference technologies

The ULCOWIN technology performance will be compared to key reference technologies to produce steel.

The main reference technology is Blast Furnace (BF), followed by Basic Oxygen Furnace (BOF).

The Direct Reduced Iron (DRI) technology can be studied as a second priority. This process is based on natural gas or hydrogen but is yet marginal with poor data availability. The possibility to find accurate inventory data to model the DRI process will be explored.

The Electric Arc Furnace (EAF) is not a direct reference as it is mostly used to produce secondary steel, and therefore will not be included in the scope of this study.

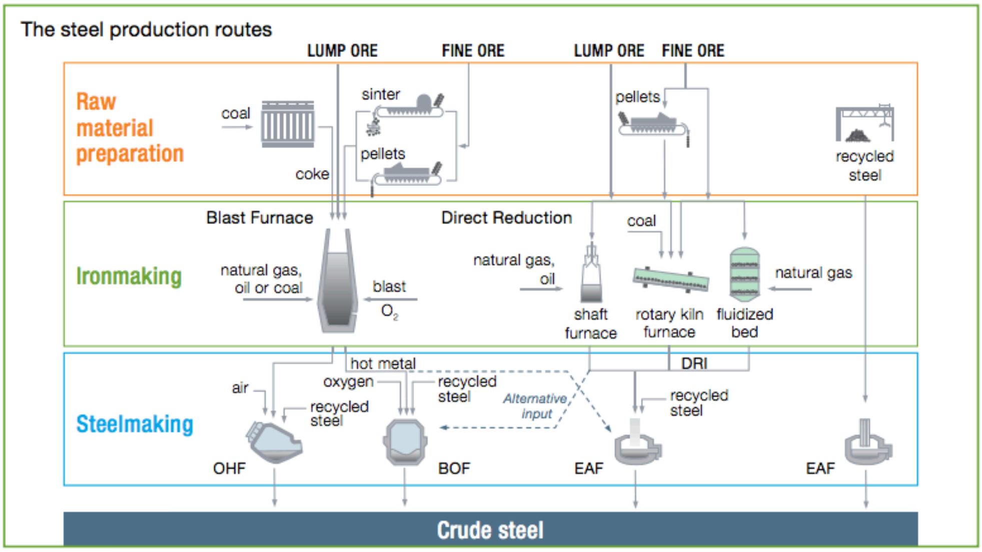

Figure 3.3: Steel production routes, from Worldsteel 2015 Steel in the circular economy, a life cycle perspective

3.4 Time horizon

The techno-economical and environmental studies will assess both the current steel production as well as future time horizons for which steel production with conventional technologies or the ULCOWIN technology will be assessed.

Current production: the production of steel with reference technologies based on 2018 data will be studied.

Future time: the production of steel with reference technologies will then be modelled for year 2030 and 2050. This model will attempt to capture the expected technology evolution. Their environmental and economic performance will be compared to the production of steel with the ULCOWIN technology based on pilot data and extrapolations.

The 2030 and 2050 models will be compared with the 2030 scenario with the European Commission emission targets for 2030 (i.e. a 40% cut in greenhouse gas emissions compared to 1990 levels, at least a 27% share of renewable energy consumption, at least 27% energy savings compared with the business-as-usual scenario) as well as the 2050 European low-carbon economy roadmap.

2030 = beginning of the ULCOWIN industrial development (first plant).

2050 = end of the ULCOWIN industrial development (100% of the European primary steel production)

3.5 Reference scenarios for RES

According to the previous part of this document, the techno-economic and environmental assessment requires a projection of the ULCOWIN industrial development on the horizon 2030 and 2050. Consequently, it needs to take into account an economic, environmental and energy reference scenario for the future of Europe, in order to define all input data needed for the study.

ULCOWIN technology is electricity-intensive, it means that its industrial development will have an impact on the European electricity system performance. Indeed, a large scale development will influence the level and profile of the European electricity consumption as a whole, but also in each country in which ULCOWIN will set up.

In addition, because an electrolysis process can have a high Demand Side Response (DSR) potential, an ULCOWIN plant could be able to contribute in the European power system balance, which has to tackle with an increasing need of flexibility due to the development of intermittent renewable energy sources (RES). In fact, the ULCOWIN industrial development in Europe should help the diffusion of RES, but also it would avoid huge investments in backup power plant, and avoid carbon dioxide emissions because backup solutions are usually based on fossil fuels.

The European power system configuration will also have an impact on the ULCOWIN cost-effectiveness, specifically in terms of electricity prices and DSR incomes. Other external factors will influence the profitability of an ULCOWIN plant, for example the development of competitors on the DSR market.

Therefore, the techno-economic and environmental assessment requires to define a development scenario for the European power system on the horizon 2030 and 2050. In order to be consistent with the European policy and vision in terms of greenhouse gases reduction and RES development, the last European reference scenario, « EU Reference Scenario 2016 - Energy, transport and GHG emissions – Trends to 2050 », is taken into account in the study, specifically the time horizons 2030 and 2050.

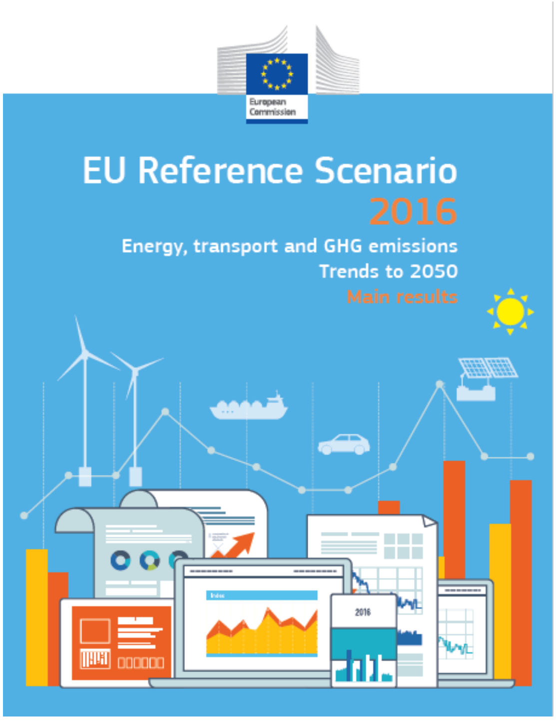

Figure 3.4: EU Reference Scenario 2016 - Energy, transport and GHG emissions – Trends to 2050

This scenario which gives a development projection of the European power system until 2050, is based on EU policies and directives decided before 2014. It was created thanks to a modelling consortium led by the National Technical University of Athens, on PRIMES model, and based on hypothesis from different European experts. It is used as a reference point for evaluation of new public policies.

The EU Reference Scenario has the advantage to be public and shared by all European partners. For instance, it is used in the European project EU-SYSFLEX, which has the objective to identify the technical problems of an important RES development in Europe, and to study solutions to deal with these problems.

The horizon 2050 of the EU Reference Scenario considers a significant part of renewables, almost 70% of the European net electricity production. This scenario gives an estimated price for carbon dioxide at 95€/t in 2050. The penetration rate considered for electric vehicles is about 46% of the European vehicle fleet.

The horizon 2030 of the EU Reference Scenario could also be taken into account in order to study the impact of the first ULCOWIN plant on the power system, considering a more conservative energy mix, in which renewables represent about 50% of the European net electricity demand, the penetration rate of electric vehicles is more about 10%, and the carbon dioxide price is about 27€/t.

More details on the EU Reference Scenario are given on the dedicated website[1]. The energy mix description for each European country and the energy prices are also provided in an annex.

4 Methodology for the process integration with renewable energies

4.1 Foreword

The objective of Task 7.2 is to evaluate how the ULCOWIN process can contribute to power system adequacy and therefore facilitate RES integration in the coming decades.

First of all, the study will evaluate the European power system profile (ENTSO-E control zone), in other words the electricity offer and demand curves, on the horizons 2030 and 2050, considering the European reference scenario, especially in terms of energy and carbon intensity. This work is necessary to define the flexibility needs of the European power system.

Then, the contribution of the ULCOWIN industrial development on the European power system will be studied: influence on the electricity demand level, so on the electricity price (offer and demand balance), DSR requests, cost of DSR contribution, and investments avoided in backup power plants.

The economic data from this integration study will finally be used by N-Side in the techno-economic study.

To do this study, the following steps are required:

1. Input data collection and hypothesis definition
2. 2030 and 2050 European power system modelling
3. Parametric assessment
4. Sensitivity study

4.2 Input data collection and hypothesis definition

All input data categories needed for the integration study are detailed in part 8.4.

For the sake of credibility and consistency with other European works, only public and official input data are used for the study. That's why data related to the European power system are extracted from the EU Reference Scenario and from ENTSO-E publications, as mentioned in part 3.5. Input data related to the iron and steel industry are extracted from famous professional associations like EUROFER and WORLDSTEEL.

Despite the richness of official sources, it is sometimes necessary to complete the data collection with hypothesis. Based on sectorial knowledge. When there is no information, the hypothesis can be defined as adjustment variables, added in the sensitivity study.

Some data or hypothesis can be common for all studies of WP7. In this case, it is the subject of discussions between the partners (conciliation meetings) in order to ensure consistency between the different studies.

4.3 European power system modelling

The 2030 and 2050 European power system modelling is mainly based on input data mentioned in part 8.4. This data collection is filled in an IT application developed by EDF to study the energy offer and demand balance.

First of all, a reference scenario is model with this application. On the basis of this reference scenario, a set of alternative scenarios is created to reflect different climate options that can have an influence on the energy production and consumption profiles, so on the offer and demand balance, flexibility needs, electricity price, etc.

4.4 Parametric assessment

After modelling, an assessment is done with the IT application to understand the European power system behavior on the horizons 2030 and 2050, considering a whole reference year as time period, climate fluctuations with influence on the RES production and the demand of electricity, and power system failures. This assessment is used to observe different phenomena that influence the DSR contribution.

The IT application developed by EDF for this kind of study, matches the production curve with the consumption one by activating production plants or DSR solutions. The activation sequence is based on the "merit order" principle, taking into account the technical constraints of each solution.

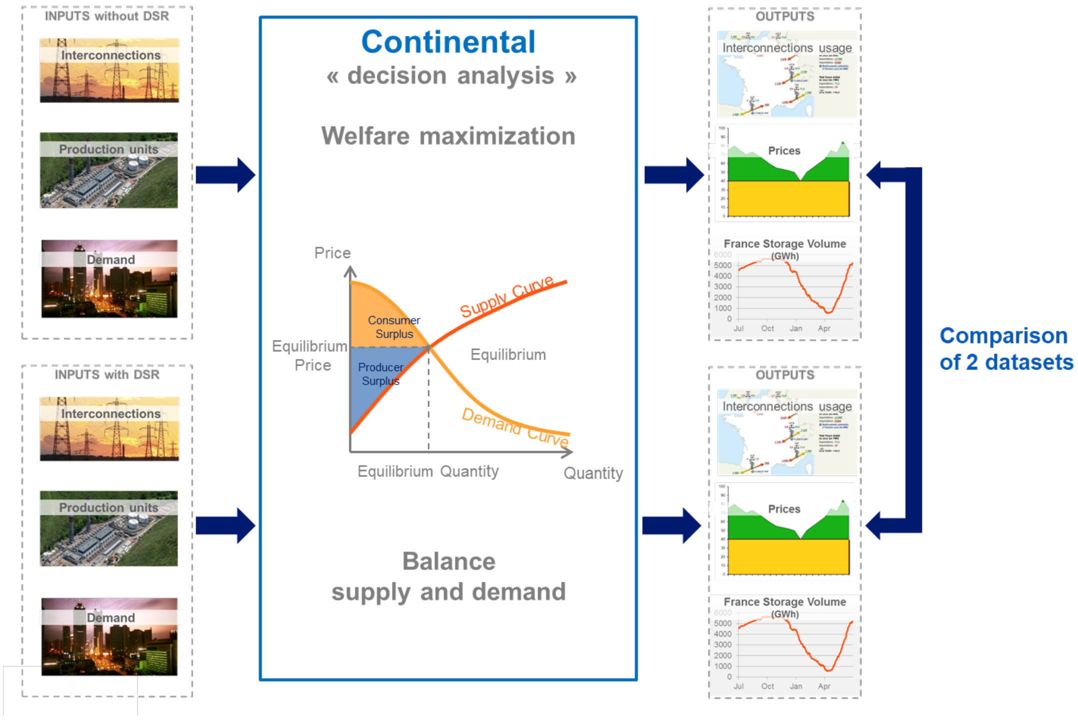

Figure 4.1: Functional diagram of EDF's software used to study the process integration with RES

The impact of the ULCOWIN industrial development on the electricity price is also studied.

Then, the contribution of an ULCOWIN steel plant in the grid balance is evaluated considering the ULCOWIN DSR profile detailed in part **Erreur ! Source du renvoi introuvable.**.

Finally, the assessment enables to define the financial savings for the European power system due to the ULCOWIN contribution in the grid balance.

Indeed, the development of DSR capacities enables two kinds of savings for the power system:

- Savings on fixed costs by avoiding for example investments in backup power plants,
- Savings on variable costs by avoiding the production of additional electricity from expensive and polluting backup power plants.

To do that, a comparison must be done, in each European country, between the power system cost structure with and without consideration of the ULCOWIN DSR potential.

The evaluation of the cost structure needs to model the energy mix in each European country and the grid interconnections between Member States.

4.5 Sensitivity study

In order to measure the sensitivity of the model, the parametric assessment step is repeated considering some hypothesis changes.

The scope of the sensitivity study will depend on the first results of the parametric assessment, and will be defined in coordination with the other WP7 partners in order to take into account the same adjustment variables.

At this stage, the adjustment variables could be for example:

- Activation cost for ULCOWIN DSR contribution,
- Available power rate for DSR,
- RES proportion in the energy mix,
- Competitors proportion for DSR (contribution of other industrial DSR capacities, of electric vehicles able to give back electricity to the grid, etc.),
- Carbon dioxide cost.

The sensitivity study will be done at European scale, but also with a focus in a selection of European countries (the main primary steel producers).

5 Methodology for integrated material and energy balances

To establish the energy and mass balances of the ULCOWIN route, three approaches are developed depending on the knowledge of the process units.

The first is related to existing and well-established process operations. Their mass and energy balances are generally well described in details in public articles. These operations are those already involved in the conventional route of primary steel production:

- The Hot Rolling that rolls the slabs into Hot Rolled Coils.
- The Lime plant that produces quick lime from calcite.
- The EAF that melts iron metal into liquid steel.

The second is related to non-existing operations which are not addressed in the SIDERWIN project. To establish their mass and energy balances analogy to existing processes are drawn or engineering data from equipment suppliers are used. These operations are closely related to metal electrowinning:

- The ultrafine grinding of iron ore to ø10µm whereinput mineral particle size has the size of Pellet feed approximated by a F80 of 60µm. The output mineral particle size has a P80 of 10µm. Ultra-fine grinding is carried out with existing equipments such as vertically stirred mills, from Bradken's Metprotec mill, Metso's Detritor mill or Netsch's ISA mill.
- The gangue is removed by leaching in alkaline solution and precipitated as silicon aluminate grossularite with lime addition. This operation is based on the analogy with Bayer process for alumina extraction from Bauxite. The iron ore is supplied as 95% hematite and purified to 98% iron oxide.

The third is related to the electrowinning step which is the specific study of the SIDERWIN study. Here the results will be derived from the measurements of the SIDERWIN cell during the trial campaign scheduled in the WP5.

6 Methodology for the environmental assessment

6.1 Life cycle assessment methodology

A leading tool for assessing environmental performance is life cycle assessment (LCA), a method defined by the International Organization for Standardization (ISO) 14040-14044 standards (ISO 2006a, b). LCA is an internationally-recognized approach that evaluates the relative potential environmental and human health impacts of products and services throughout their life cycle, beginning with raw material extraction and including all aspects of transportation, manufacturing, use, and end-of-life treatment. It is important to note that LCA does not exactly quantify the real impacts of a product or service due to data availability and modelling challenges. However, it allows to estimate and understand the potential environmental impacts which a system might cause over its typical life cycle, by quantifying (within the current scientific limitations) the likely emissions produced and resources consumed. Hence, environmental impacts calculated through LCA should not be interpreted as absolute, but rather relative values within the framework of the study. Ultimately, this is not a limitation of the methodology, since LCA is generally used to compare different systems performing the same function, where it’s the relative differences in environmental impacts which are key for identifying the solution which performs best.

Among other uses, LCA can identify opportunities to improve the environmental performance of products, inform decision-making, and support marketing, communication, and educational efforts. The importance of the life cycle view in sustainability decision-making is sufficiently strong that over the past several decades it has become the principal approach to evaluate a broad range of environmental problems, identify social risks and to help make decisions within the complex arena of socio-environmental sustainability.

Through the use of LCA, the environmental performance of the ULCOWIN technology can be quantitatively compared to a conventional steel production technologies through several key indicators.

In particular, the carbon footprint of the ULCOWIN technology using different future scenarios for electricity mixes will be assessed. The work performed in WP6 to study the potential use of alternative raw materials in the ULCOWIN process, i.e. red mud from the Bayer process applied in aluminium industry or zinc and nickel by-products, will also be evaluated through the LCA. A conventional scenario using iron ore will be compared to scenarios using the latter alternative raw materials.

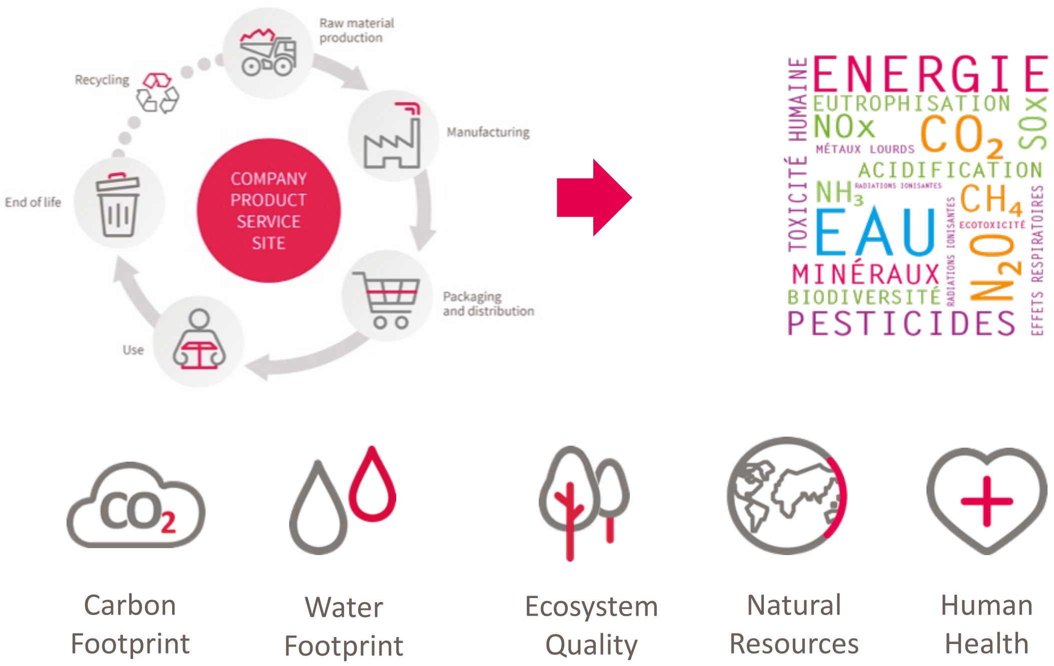

Figure 6.1: Life Cycle Assessment framework, from product life cycle inventory to environmental indicators

6.2 Most relevant indicators for LCA

Life Cycle Impact assessment classifies and combines the flows of materials, energy, and emissions into and out of each product system by the type of impact their use or release has on the environment.

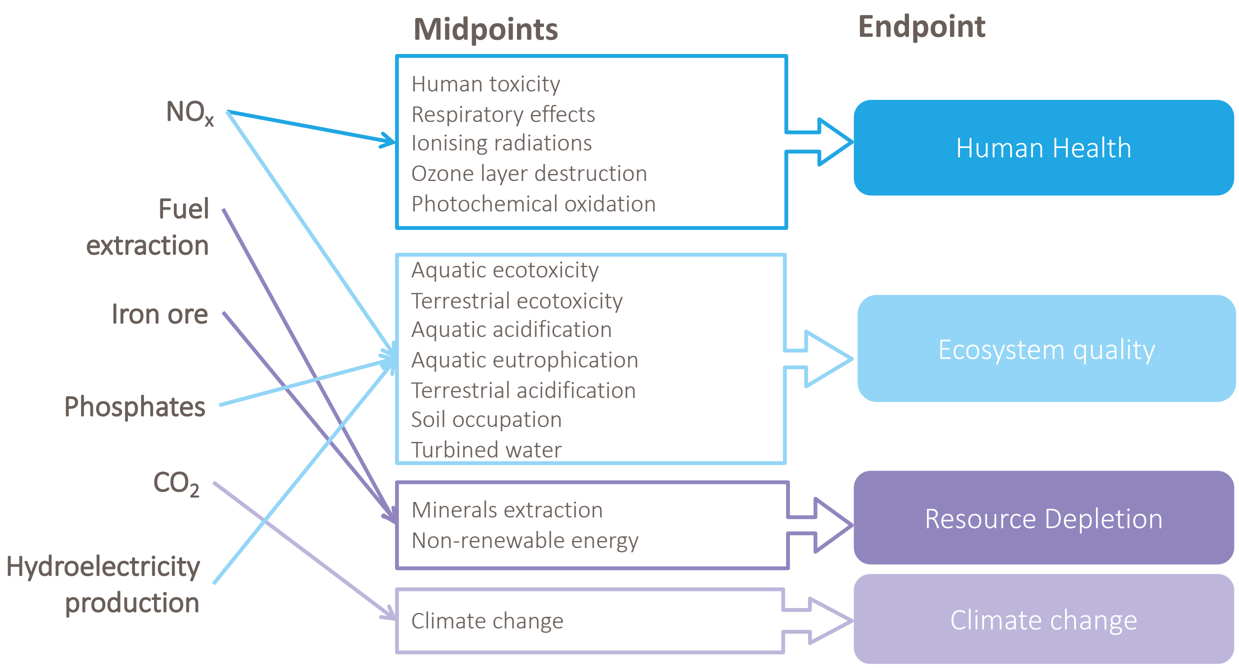

Figure 6.2: Impact assessment framework

The method used here to evaluate environmental impact is the Environmental Footprint (EF) method (European Commission 2017). This method assesses 16 different potential impact categories (midpoint). It is the result of a project for the European Commission that analyzed several life cycle impact assessment (LCIA) methodologies to reach consensus. It is the official method to be used in the Product Environmental Footprint (PEF) context of the Single Market for Green Products (SMGP) initiative (European Commission 2013).

Table 6.1 describes the models used for each of the 16 indicators that will be considered in the environmental study.

Table 6.1: Indicators and related assessment models used

Impact category or LCI indicator	Model	Unit	Source	Class
Climate change	Bern model – Global Warming potentials (GWP) over a 100-year time horizon	kg CO_2 eq	(IPCC 2013)	I
Ozone depletion	EDIP model based on the ODPs of the WMO w/ infinite time horizon	kg CFC-11 eq	(WMO 1999)	I
Human toxicity – non-cancer effects	USEtox® model	CTUh	(Rosenbaum et al. 2008)	III (interim)
Human toxicity – cancer effects	USEtox® model	CTUh	(Rosenbaum et al. 2008)	III (interim)
Particulate matter	PM method recom-mended by UNEP	Deaths/kg $PM_{2.5}$emitted	(Fantke et al. 2015)	I
Ionising radiation	Human Health effect model	kg U^{235} eq	(Dreicer et al. 1995)	II
Photochemical ozone formation	LOTOS-EUROS model	kg NMVOC eq	(van Zelm et al. 2008)	II
Acidification	Accumulated Exceedance model	mol H+ eq	(Seppälä et al. 2006; Posch et al. 2008)	II
Terrestrial eutrophication	Accumulated Exceedance model	mol N eq	(Seppälä et al. 2006; Posch et al. 2008)	II

Freshwater eutrophication	EUTREND model	kg P eq	(Goedkoop et al. 2009)	II
Marine eutrophication	EUTREND model	kg N eq	(Goedkoop et al. 2009)	II
Freshwater ecotoxicity	USEtox® model	CTUe	(Rosenbaum et al. 2008)	III (interim)
Mineral & metal resource depletion	CML 2002 model (abiotic depletion – ultimate reserves)	kg Sb eq	(Guinee 2002; van Oers et al. 2002)	III
Non-renewable energy resource depletion	CML 2002 model (abiotic depletion – fossil)	MJ	(Guinee 2002; van Oers et al. 2002)	III
Land use	Soil Quality Index (based on the LANCA model)	points	(Beck et al. 2011)	III
Water scarcity footprint	AWARE 100 model	m^3 water deprived eq	(Boulay et al. 2017)	III

These impact categories are further described in Annex 12.1.

A specific focus will be brought on the following key indicators given their importance for the steel production sector:

- GHG emissions
- Non renewable primary energy use
- Water use
- Land use

In addition, two endpoint indicators will be assessed to provide a more comprehensive overview of environmental impacts: human health and ecosystem quality.

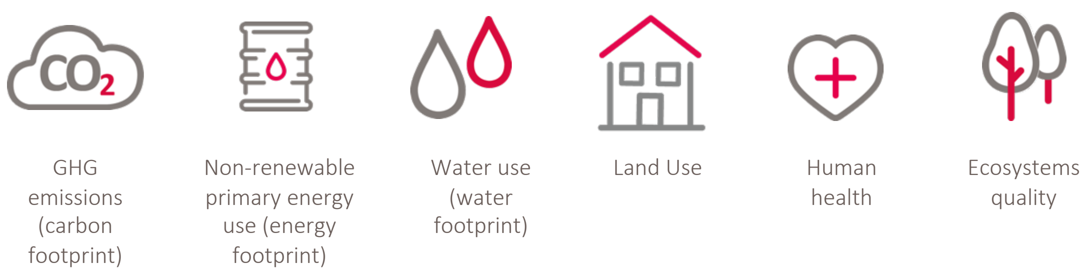

Figure 6.3: Key indicators assessed in the environmental study

7 Methodology for the techno-economic assessment

This part provides a description of the techno-economic analysis methodology, objectives and boundaries.

The general purpose of the techno-economic analysis consists in evaluating and comparing profitability metrics for the ULCOWIN technology and other reference steel-manufacturing technologies. These metrics will be based on a cost-revenue model which comes from (Morrow, 2015), and that will be adapted and possibly extended for the sake of this analysis.

In addition, these metrics will be applied to a series of different *cases*. A *case* represents a hypothetical situation which is defined by different factors of influence, i.e. the considered technology, the time framework, the location and a scenario characterizing future energy market trends.

The following part presents the cost-revenue model which will be used to perform the analysis, as well as some possible profitability metrics which can be relevant. Then in part 7.2, the different factors of influence (impacting the different analysis parameters) are explained and justified. Part 7.3 provides the market scenario structure and some preliminary data from the literature. Then part 7.4 gives a listing of the different assumptions made for the analysis, and allowing to define some boundaries on its content and scope.

7.1 Techno-economic analysis LMC model

The techno-economic analysis aims at evaluating different profitability measures so as to compare ULCOWIN technology with the reference BF–BOF technology, as it is one of the most widespread and standard route. The main profitability metric which will be used to perform this comparison is the levelized manufacturing cost (LMC), as established in (Morrow, 2015).

This LMC KPI is defined in this article as “the minimum per-unit price which is necessary to recover all of the costs associated with manufacturing a product over an assumed financial cycle and manufacturing facility lifetime”. This metric is considered to be relevant for our techno-economic assessment, since we compare steel-manufacturing technologies at fixed and identical yearly production capacities (as further explained in part 7.4).

The LMC is determined based on the Net Present Value (NPV) of all costs within a pre-defined time horizon (financial lifecycle) that should correspond to the manufacturing facility lifetime. This time horizon will need to be determined in accordance with the LCA assumptions. In addition, the analysis will possibly be extended to evaluate the NPV of all costs on varying horizons and evaluate the corresponding Return On Investment (ROI) based on the total CAPEX (capital expenditure).

The revenue-cost model which will be used to estimate the LMC includes various components which are presented in Table 7.1. The first category includes the total CAPEX which corresponds to any initial investment to be made for deploying a full industrial-scale steel-manufacturing plant. The Operation & Maintenance (O&M) category essentially includes labour costs and general plant upkeep, but does not include raw materials and energy use which are gathered in the next separate categories. A dedicated category includes the costs incurred related to Greenhouse Gases (GHG) and other polluting gases emission allowances, as this is a central factor differentiating the ULCOWIN technology from the traditional steel-manufacturing technologies. Finally, a last category includes other costs such as export costs of finished products.

Table 7.1: Listing of components to be included in the cost–revenue model

Category	Description of costs and revenues
Capital (CAPEX)	Cost of land use
	Infrastructure
	Technology equipment
	Equipment installation and assembly
O & M	Maintenance costs
	Labour costs
Raw materials and consumables (transport and acquisition)	Iron ore
	Steel scrap
	Ferroalloys
	Limestone
	Olivine
	Refractories
Energy and fuel use	Electricity consumption from RES
	Electricity consumption from conventional sources
	Electricity re-injection from local surplus
	Natural gas consumption
By-products transport, disposal and/or reselling	Slag reselling
	Scrap steel
	Oxygen valorisation
Environmental allowances: direct and indirect cost	Cost of CO_2 emissions
	Cost of CO emissions (if any)
	Cost of SO_x emissions (if any)
	Cost of NO_x emissions (if any)
	Cost of SO_x/NO_x/CO treatment (equipment and O&M)
Other	Transportation of finished product (HRC)

Note that this is an initial basis for the cost-revenue model which could possibly be further refined during the course of the analysis, based on available data and requirements.

Most of these costs and revenues will be determined based on both quantity or resource use (e.g. amount of iron ore measured at process input in tons) and market parameters. Except for the capital costs, the price of almost every entry of the preceding table is related to an evolving market (for which different scenarios can be considered). The various market parameters are listed in Table 7.2.

Table 7.2: Listing of the various market parameters impacting the LMC KPI

Category	Market parameter	Unit
Energy market price	Electricity buying price	€ (2020)/MWh
	Electricity selling price	€ (2020)/MWh
	Natural gas price	€ (2020)/GJ
	Coal price	€ (2020)/ton
	Coke price	€ (2020)/ton
GHG emission allowances	CO_2-equivalent emission fees	€ (2020)/ton
Raw materials	Iron ore (BF–BOF quality level) price	€ (2020)/ton
	Iron ore (ULCOWIN quality level) price	€ (2020)/ton
	Steel scrap buying price	€ (2020)/ton
	Steel scrap selling price	€ (2020)/ton
	Ferroalloys prices	€ (2020)/ton
	Limestone price	€ (2020)/ton
	Olivine prices	€ (2020)/ton
	Compressed oxygen price	€ (2020)/Nm^3
	Refractory materials prices	€ (2020)/ton

Most of these market parameters will be impacted by time and some could possibly be impacted by location as well (due to logistics costs), as further detailed in part 7.2. The different market scenarios considered in the analysis will apply to the energy market parameters and GHG emission allowances, while raw materials markets will not be impacted by such scenarios. The purpose is thus to make assumptions on energy market trends rather than steel market trends. Although there are uncertainties on the future trends on raw materials and by-product market, the focus is rather put on energy market for the modelling of uncertainty, so as to set some boundaries on the number of cases to include in the analysis. The other reason behind such assumption is that ULCOWIN and BF-BOF have a similar materials' efficiency in terms of iron ore, which is the main raw material on which scenarios could be built (which would not be essential due to this similarity).

The choice to use € (2020) monetary units is motivated by the fact that lots of cost and price data still need to be collected and quantified along the course of the project. But the precise reference year might be modified later on based on data collection process. Still, the methodology remains the same to consider the € value at a reference year which is supposed to represent present time.

Finally, a few financial parameters will be adjusted to frame the analysis, such as

- the plant reference lifetime used as financial cycle length for evaluating the NPV of cost cash flows,
- the actualization rate used to calculate the NPV of future cash flows to be evaluated in $€_{2020}$,
- specific inflation or growth rates to be applied on certain market prices, if applicable

7.2 Factors of influence

The computation of the LMC criterion used to compare the ULCOWIN technology and the traditional BF-BOF route relies on various parameters. As explained in the previous section, these parameters range from materials and energy balance flow quantities (like iron ore input) to the different market prices and rates impacting costs and revenues.

The techno-economic analysis will consist in evaluating the LMC KPI considering multiple values for each parameter. The parameters' values vary based on what will be referred to as *factors of influence*. Overall, the analysis integrates four distinct factors of influence:

1. the technology (either ULCOWIN or BF-BOF route),
2. the time horizon (e.g. now, 2030 and 2050),
3. the geographic location of the plant, and
4. the assumed scenario characterizing future market trend.

In order to frame the techno-economic analysis, for each analysis parameter (such as coal market price or electrolysis cell efficiency), the impacting factors of influence will be identified, i.e. the factors that have an influence on the parameters' value.

The technology is probably the most obvious factor of influence, as it will impact every technical parameter characterizing the operational condition of the conceptual plants to be compared with one another. These technical parameters typically include energy and materials efficiency, products recipes, equipment features and costs, land use, etc.

The time factor is also quite essential as the electrowinning technology is not expected to be fully deployed before 2040 horizon, according to (EUROFER, 2013). The time factor will typically impact the market parameters for raw materials, energy, GHG allowances and possibly by-products. Optionally, if the related data can be quantified, the parameters characterizing technology equipment (such as installation costs, O&M costs, materials and energy efficiencies) could take different values at different time horizon (reflecting the evolution of technology's maturity). If this evolution cannot be predicted with sufficient reliability, then these parameters will instead be considered as constant over the whole time horizon.

The geographic location is included as a factor to be refined later in the analysis. The goal is to consider reference plant locations across Europe to consistently represent the way the European steel market is geographically spread. Hence, the analysis will include the 3 to 10 countries with the largest yearly crude steel production over the last 5 years, as listed in (EUROFER, 2018). The location factor will mostly impact land cost, supply chain costs and possibly labour costs as well.

Finally, the assumed scenarios on energy market are considered as the last factor of influence. These correspond to empirical assumptions which are made on future trend of energy generation and prices, based on reference works of the literature such as (Pardo, 2013). These market scenarios will also be used to assess the evolution of GHG emission allowance rates.

The following table indicates which factors (amongst technology, time, location and market scenario) have an influence on the most important parameters of the analysis.

Table 7.3: Relation between factors of influence and parameters of the analysis

Parameters	Factors of influence			
	Technology	Time	Location	Market scenario
Equipment costs (acquisition and assembly)	yes	no	no	no
Land use and infrastructure value	yes	no	yes	no
Equipment O&M costs	yes	no	no	no
Energy efficiency	yes	no	no	no
Materials consumption	yes	no	no	no
Polluting gases emissions	yes	no	no	no
By-product generation	yes	no	no	no
Electricity prices (buying & selling)	no	yes	yes	yes
Natural gas price	no	yes	yes	yes
Coal price	no	yes	yes	yes
GHG emission allowance rates	no	yes	no	yes
Price of raw materials	no	yes	no	no
By-product reselling price / waste disposal costs	no	yes	no	no
Transport costs for raw materials & by-products	no	yes	yes	no

The relations presented in the table above involves several important assumptions which are further detailed in part 7.4.

The land use and infrastructure value might be similar when comparing an ULCOWIN plant to a traditional BF-BOF plant. If the difference appears to be negligible, these parameters will then not be considered in techno-economic analysis framework.

7.3 Reference market scenarios

This part provides a description of the reference market scenarios which will be considered in the framework of the techno-economic analysis. The purpose of these scenarios is to represent the uncertainty on future energy market trends, which will largely impact the respective economic performance of BF-BOF and ULCOWIN technologies.

As indicated in tables 7.2 and 7.3, the reference scenarios which will be considered within the analysis cover four specific variables linked to energy market and emission allowances:

- Electricity price,
- Natural gas price,
- Coal price,
- CO_2-equivalent GHG emission allowance rate.

These are the four main parameters which will vary depending on the market scenario, as indicated in table 7.3. One should note that the metallurgical coke price is left out of this list. The reason is that its price is supposed to be highly correlated with coal price, and is more linked to raw materials market than energy market.

The analysis will not consider different scenarios regarding raw materials or by-products prices. The assessment will thus only consider scenario variations on future energy and GHG market trends due to their high uncertainty, while assuming rather standard trends on steel raw materials market. However, all parameters linked to raw materials will still impacted by the time factor, which already requires a general hypothesis on the expected evolution of these prices, but considering only one single standard scenario.

As it is common practice in long term techno-economic assessment, this analysis will rely on three main scenarios to characterize future market trends:

1. A standard scenario: it assumes a continuum on the evolution of RES development in Europe and progressive decarbonisation based on EU countries commitments and targets. This scenario will serve as a baseline.
2. A favourable scenario: in this scenario, the integration of RES in European energy mix exceeds the usual expectations, leading to decreased electricity prices (but possibly an increased volatility on supply, and hence on prices as well), while fossil fuel costs exceed the usual projected growth. This scenario is obviously favourable to the integration and development of the ULCOWIN technology.
3. An unfavourable scenario: this scenario is basically the opposite of the previous one. In this case, it is assumed that decarbonisation targets of the European member countries are only partially met, with electricity prices staying relatively stable in terms of average value over the 2050 horizon, while fuel costs increase less than expected. This scenario is once again referred to as *unfavourable* with respect to the ULCOWIN technology characteristics (while being more advantageous for the traditional BF-BOF route).

The structure of these market scenarios is inspired from the literature and in particular the previous techno-economic assessment of Fischedick et al.

(Fischedick, 2014) and European Commission report (Pardo, 2013). The actual data for the scenarios' parameters is also taken from these two sources and summarized in the table below.

Table 7.4: Reference scenarios on energy market trends

Scenario	Year	Price data			
		Electricity (€/MWh)	Natural gas (€/GJ)	Coal (€/t)	CO2 allow. (€/t)
Favourable	2020	91	8.1	235	27
	2030	85	10.5	324	45
	2040	66	12.7	448	60
	2050	40	14.9	618	75
Standard	2020	85	7	200	23
	2030	78	8.3	235	34
	2040	70	9.6	277	45
	2050	58	10.6	326	57
Unfavourable	2020	74	6.1	184	20
	2030	71	6.6	200	26
	2040	67	7.3	217	36
	2050	62	8.1	236	45

These figures are provided in (Fischedick, 2014) for the case of Germany. Hence, a first objective of the techno-economic analysis will be to generalise these data to other significant EU locations based on adaptation factors. Besides the scenarios on energy market, this latter source also provides valuable information on expected trends on raw materials market, in particular for iron ore prices and price of metallurgical coke.

The scenarios on coal price were deduced from (Pardo, 2013), considering a growth rate of 1.64%. For the favourable scenario, this growth rate is supposed to be doubled, while it is halved in the unfavourable scenario.

Finally, these values are supposed to be refined or updated later on, in order to express these prices in terms of $€_{2020}$. Besides, the values for year 2020 should be harmonized later on, considering that this information will be better known at that time.

7.4 Assumptions for the analysis

In this part, the various assumptions made for the analysis are listed, described and motivated. Most of these assumptions are made to define boundaries to the techno-economic assessment. This list is non-exhaustive as additional hypotheses might be taken later on, based on data collection process, actual data availability or feedback from project partners.

a) Reference technologies

The analysis will consist in studying and comparing two reference technologies (or production routes), which are

- The innovative ULCOWIN technology, and
- The traditional BF-BOF process.

For each technology, a conceptual plant will be modelled and analysed to compute profitability KPIs such as the LMC.

b) Plant production capacity and finished product

These conceptual plants will be characterized by a given fixed production capacity, expressed in tons/year. Based on the LMC KPI, this production capacity is not expected to have an influence on the techno-economic performance measures and is therefore not considered as an analysis parameter *per se*.

These plants will also be harmonized with respect to the type of finished product at their output, i.e. HRC steel, or hot rolled coils (which is a standard product described in part 3.1).

c) Independency with respect to steel finished product demand

It is assumed that the two theoretical plant to be assessed within the analysis have an HRC steel production that is fully covered by demand. Considering the LMC KPI, neither the revenue from selling the finished product nor the HRC steel demand will have an impact on the techno-economic performance metric, no matter which time frame and which location is considered.

d) Geographical location

The LMC KPI will be measured for the two technologies and assuming different possible locations for the conceptual plants. The locations will be chosen so as to represent the European countries having the most significant steel production over the last 5 years as given by (EUROFER, 2018). This is an approach which was originally suggested by EDF for its own analysis on RES integration.

Depending on data availability, this exact list of countries will be established later on along the course of the analysis. The analysis should normally include at least 5 of the following countries: Germany, Italy, France, Spain, UK, Poland, Austria, Belgium, Netherlands and Czech Republic.

e) Time frame

The steel production technologies will be compared at different time horizon, i.e. from now until 2050. This factor will mostly impact energy and raw materials market prices. Optionally, this factor could also influence materials and energy efficiency of the different technologies. Depending on data availability (requiring assumptions on evolution of technology performance), this time-variability on process efficiency could be integrated in the techno-economic analysis framework.

f) Polluting gases and techno-economic impact

The techno-economic analysis integrates penalties and treatment costs for polluting gases emissions. For CO2 emissions, a certain allowance price will be considered, as stated in table 7.4. For other types of pollutants, two possibilities will be considered:

1. Use a CO_2 equivalent factor and apply it to measure the economic impact in terms of allowances
2. Consider an upper limit on emission for specific gases (notably for which no CO_2-equivalent factor exists) and add the indirect cost of exhaust gases treatment in the relevant cost categories.

The latter approach will be used notably for non-GHG gaseous pollutants such as NO_x, SO_x and CO. For these gases, the European regulation imposes industry-specific emission limits. If these thresholds appear to be exceeded, exhaust gas treatment units might have to be installed, with related costs of additional investment and impact on parameters such as energy consumption. For the sake of the present techno-economic assessment, we will assume that the work of ensuring that present and forecasted future emission limits are respected, will be done as part of the environmental assessment (LCA) performed by Quantis. Thereby, any indirect cost related to the treatment of excessive NO_x, SO_x or CO emissions will be directly integrated in the respective cost categories (CAPEX, O&M, energy use…).

8 Data collection management plan

8.1 Data exchange with other H2020 projects

The European Commission provides an important support to the EU steel industry (Rossetti 2017) through several funded research projects. For instance, the Research Fund for Coal and Steel (RFCS) supports research and innovation projects in coal and steel sectors. One RFCS projects called *LowCarbonFuture* summarizes, evaluates and promotes research projects and knowledge dealing with CO_2 mitigation in iron and steelmaking. It will generate a roadmap stating research needs, requirements and boundary conditions for breakthrough technologies and a new CO_2 lean steel production to guide the EU steel industry towards the world's climate agreeements and the EU climate goals (EU Commission 2018).

We plan to contact the *LowCarbonFuture* consortium and suggest to exchange data with other H2020 projects on low carbon steel production. The data requirements listed in next paragraphs will be discussed with members of the *LowCarbonFuture* consortium.

8.2 Data requirements for LCA and LCC

Life cycle inventory (LCI) data collection mainly concerns the materials used, the energy and resources consumed as well as the wastes and emissions generated by each process included in the system boundaries.

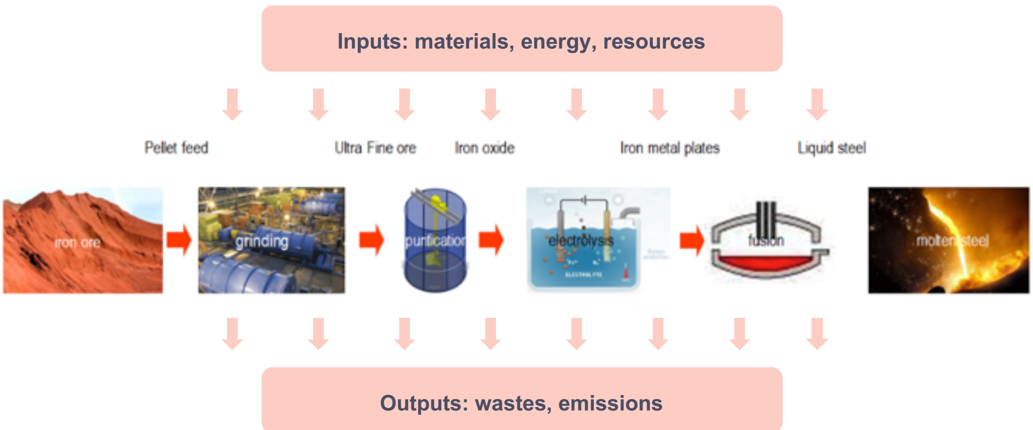

Figure 8.1: Summary of data requirements for LCA

Primary data will be collected from ArcelorMittal for the steel production with the ULCOWIN technology as well as reference technologies.

Additional information describing the remaining aspects of the life cycle will be collected from a variety of publications and experts.

All life cycle inventory data sources are from the ecoinvent database v3.3 in the cut-off by classification allocation model. Ecoinvent is recognized as one of the most complete background LCI databases available, from a quantitative (number of included processes) and a qualitative (quality of the validation processes, data completeness, etc.) perspective. Historically focused on European production activities, it has reached a global coverage of thousands of commodities and industrial processes.

More specifically, the process of hot rolled coil production "Steel, low-alloyed, hot rolled {RER}| production | Alloc Rec, U" will be used as a benchmark reference for primary data collected from ArcelorMittal.

For the ULCOWIN technology, a first set of data is already available from the former IERO project. Data will be updated following an iterative process, according to the plan below, following different stages of the pilot construction.

Iterations for ULCOWIN data

- Iteration 0: First data from IERO project
- Iteration 1: Final data from IERO project
- Iteration 2: pilot design at M24 (check WP4)
- Iteration 3: pilot construction at M36 (experimental data), tests until M60 (check WP5)
- Iteration 4: pilot upscaling (pilot designed for 50 kg steel/day)

Figure 8.2 shows a summary of inputs and outputs for the ULCOWIN process as the final data from the IERO project (iteration 1).

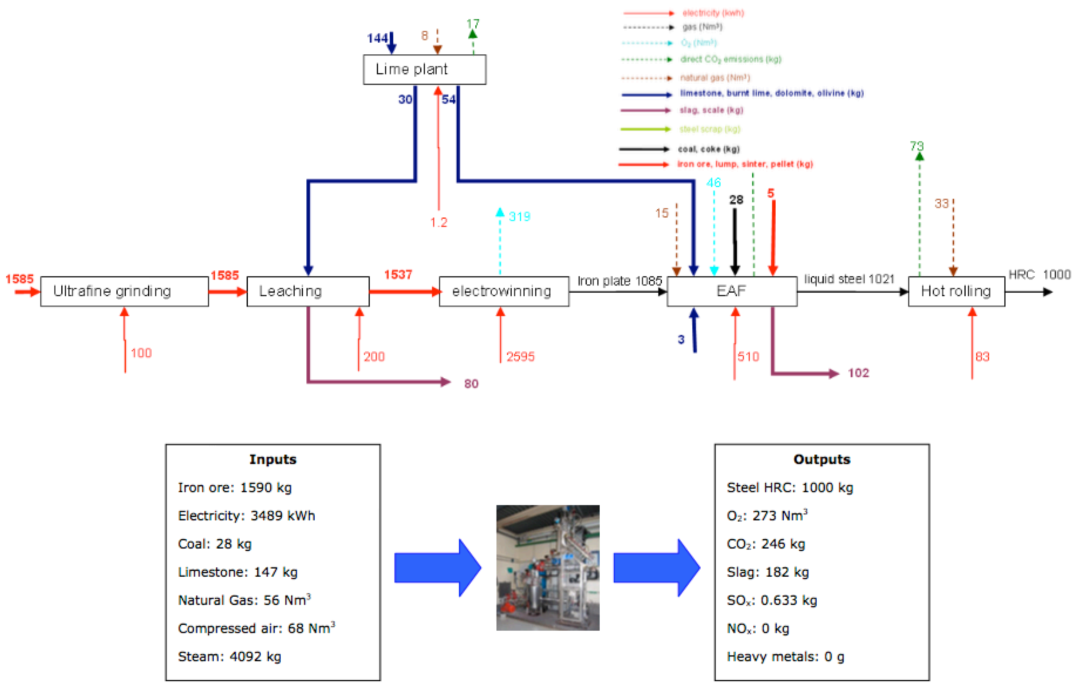

Figure 8.2: Flow sheet of the ULCOWIN route and overall mass and energy balances (iteration 0)

The complete data collection form is presented in the file Siderwin_data_form_2018-08-29 (available on the collaborative platform: https://seraing.cmigroupe.com/metals/projects/B007F.00231/CollaborativePlatform/_layouts/15/WopiFrame.aspx?sourcedoc=/metals/projects/B007F.0023

1/CollaborativePlatform/6%20Deliverables/D7.1/Siderwin_data_form_2018-08-29.xlsx&action=default).
The electricity mix used by the ULCOWIN technology in 2030 and 2050 will be based on electricity mix projections determined in task T7.2.

8.3 Data requirements for the techno-economic analysis

This part provides a summary of data and information requirements in the framework of the techno-economic analysis, as well as the possible project participants who could contribute to the data collection process.

a) Technology-related data

This category includes all information and data related to materials and energy efficiencies, as well as the equipment costs, operations and maintenance costs. These should be collected in collaboration with AMMR and technology manufacturer/designers.

The materials and energy data (scaled per ton of steel HRC) required for the analysis are the following:

- Raw materials input (iron ore, scrap, limestone, oxygen, etc),
- Fossil fuel input (natural gas, coal, coke, diesel),
- Electricity input,
- By-product output (oxygen, slag, scrap, etc) and possible waste disposal costs,
- Polluting gas emissions (CO_2, CO, SO_x, NO_x)

In addition, internal mass and energy flows should ideally be determined to enable a consistent and exhaustive analysis. Also concerning by-products, each of these should be identified as “valuable for reselling”, “waste” and/or “internally re-usable”.

The data linked to equipment costs required for the analysis are the following:

- Equipment acquisition and installation costs,
- Equipment operation and maintenance costs,
- Land use and infrastructure costs

These three latter pieces of information should be specified for a given plant production capacity (in tons of HRC steel per year). Land use, infrastructure and O&M costs could possibly be location-dependent, considering (notably) labour costs differences between different geographical locations.

b) Energy market data

The energy market data are quite central in the techno-economic analysis. Several reference scenarios are considered as detailed in part 7.3. These data should be collected both in collaboration with EDF and AMMR, but some information can also be taken from the literature or online resources (such as the website www.steelonthenet.com). The energy market data include the following:

- Electricity prices,
- Natural gas prices,
- Coal (and possibly coke) market prices.

These values are expected to vary along time and should thus be determined over the whole 2020-2050 horizon. Besides, the favourable, standard and unfavourable scenarios will also impact those values as illustrated by table 7.4.

c) Raw materials and by-product market data

Raw materials and by-product market data are almost equally important as energy market data. However, in the framework of the techno-economic analysis, only one single standard scenario will be considered to characterize the evolution of the raw materials and by-product market prices, unlike the energy market reference scenarios. These data should be collected in collaboration with AMMR, and also extracted from the literature.

These price data mostly include:

- Iron ore prices,
- Scrap buying price,
- Price of ferroalloys,
- Price of limestone,
- Slag reselling price,
- Scrap reselling price.

All these prices are also time dependant, which requires assumptions on expected growth rates to deduce price at the 2020-2050 horizon.

Concerning iron ore prices, a distinction should be made between ULCOWIN-specific and BF-BOF–specific quality levels, considering that these are characterized by different prices.

Besides the price data for the material itself, location-specific data should also be determined to characterize transport costs (i.e. supply chain costs). Once again, these transport costs should be quantified in collaboration with AMMR (as few information is expected to be found in the literature in this field).

d) Environmental costs and restrictions

Finally, a few key variables should be quantified to integrate environmental costs and restrictions. These data should be collected in collaboration with Quantis, taken from the literature, or deduced from existing European policies. These data include:

- CO_2 emission allowances,
- CO_2 equivalent factors for other polluting gases (if applicable),
- Restriction on maximum allowed emission levels (if applicable, e.g. for SO_x and NO_x),
- Acquisition and assembly cost of gas treatment technologies (e.g. for SO_x and NO_x),
- Operation and maintenance costs of gas treatment technologies.

CO_2 emission allowances are time- and scenario-dependent variables. The other variables are supposed to be independent of these two factors of influence.

e) Miscellaneous data and information

In addition to the previously listed data, the analysis also requires some general parameters to be quantified. First, as the LMC criteria relies on NPV evaluated over a certain life cycle, the exact duration of this financial life cycle should be determined. This duration should be defined in accordance with Quantis' LCA so as to reflect actual technology lifespan through the life cycle length.

The LMC criteria and NPV computation should also rely on actualisation rate and various growth rates (on energy prices, prices of raw materials, labour rates, etc) which should be defined in accordance with EDF's and AMMR's knowledge in the various related field.

8.4 Data requirements for the process integration with renewable energies

The study of the process integration with RES on the horizons 2030 and 2050 needs the following data:

- Energy mix, demand level, energy and CO_2 prices … (data from EU Reference Scenario 2016),
- Grid connections between European countries (data from ENTSO-E and e-Highway 2050 publications),
- ULCOWIN industrial development hypothesis (data from the previous European project IERO, and hypothesis),
- ULCOWIN DSR profile (data from SIDERWIN – WP2 – T2.5),
- European steel industry development (data from professional associations like EUROFER and WORLDSTEEL),
- Fixed costs (including investment costs) of electricity plants (extrapolations based on RTE publications).

The ULCOWIN DSR profile depends on the conclusions of the work packages 2 and 3. Indeed, the theoretical DSR profile is defined in task 2.5, and the influence of electrolysis interruption is studied in task 3.3.

The following theoretical DSR profile as been defined in tandem with ArcelorMittal in task 2.5:

- Available power:
  Between 36% and 92% of the electrolysis power (electrolysis and zinc industry feedback).
- Notice period:
  ULCOWIN is a reactive model (modelling without notice period).
- Activation period:
  ULCOWIN is a reactive model (modelling without activation period).
- Duration:
  Between 1 and 2 hours (electrolysis feedback with thermal inertia issues). No duration constraint to consider in the model in order to evaluate the whole DSR potential. If a need for long term DSR requests is observed in the study, this conclusion will help to decide if a thermal conditioning must be designed in order to maximize the DSR potential.
- Frequency:
  No limit of frequency.
- Calendar:
  No calendar constraint to consider in the model. If the DSR requests are concentrated in the same period of time, it will help to program the periodic maintenance operations.

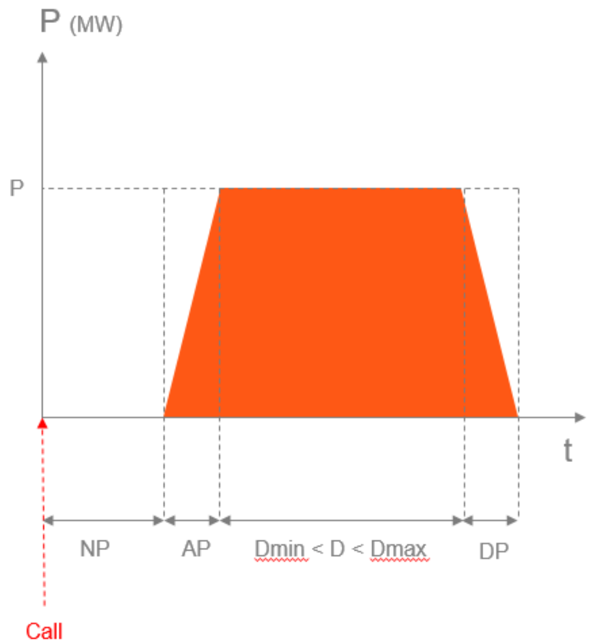

Figure 8.3: Definition of a DSR profile

The minimum ULCOWIN DSR cost taken into account is the loss of income due to production stops. This information is given by N-Side (from the techno-economic study T7.5).

On the contrary, some data used or produced in this integration study will be used as input data in the other WP7 studies. This is the case in particular for the following data:

- European energy mix : information needed in the environmental assessment (T7.4),
- Electricity and carbon dioxide costs : information needed in the techno-economic study (T7.5),
- ULCOWIN DSR contribution : information needed in the techno-economic study (T7.5),

The links between the different data collections for each WP7 studies require to ensure consistency between partners' roadmaps, and to confer before defining the adjustment variables for the sensitivity study.

8.5 Data requirements summary

Table 8.1 presents the summary of data requirements for tasks 7.2, 7.4 and 7.5, including the output data reused in other tasks.

Table 8.1: Summary table of data requirements for tasks 7.2, 7.4 and 7.5

Data type	Data source
T7.2 Data requirements for the process integration with renewable energies	
• Energy mix, demand level, energy prices	Data from EU Reference Scenario 2016
• Grid connections between European countries	Data from ENTSO-E (TYNDP) and e-Highway 2050 publications
• ULCOWIN industrial development hypothesis	Hypothesis and data from European project IERO
• ULCOWIN DSR profile	Data from SIDERWIN – WP2 – T2.5 and WP3 – T3.3
• European steel industry development	Data from professional associations like EUROFER and WORLDSTEEL
• Fixed costs (including investment costs) of electricity plants	Extrapolations based on RTE publications (RTE is the French electricity network operator)
• Minimum ULCOWIN DSR cost taken into account (the loss of income due to production stops)	Provided by N-Side as output of the techno-economic study T7.5
T7.2 output data	
• European energy mix • Electricity and carbon dioxide costs • ULCOWIN DSR contribution	• Data provided by EDF, • Reused for T7.4 and T7.5
T7.4 and T7.5: Technology related data	
• Raw materials input (iron ore, scrap, limestone, oxygen, etc) • Fossil fuel input (natural gas, coal, coke, diesel) • Electricity input • By-product output (oxygen, slag, scrap, etc) and possible waste disposal costs • Polluting gas emissions (CO_2, CO, SO_x, NO_x)	• IERO project • Ecoinvent v3 database • ULCOWIN: T7.3 results
T7.4 and T7.5: Energy market data	
• Electricity prices • Natural gas prices • Coal (and possibly coke) market prices	• EDF T7.2 • Literature or online resources

T7.4 and T7.5: Raw materials and by-product market data	
• Iron ore prices • Scrap buying price • Price of ferroalloys • Price of limestone • Slag reselling price • Scrap reselling price	AMMR, and also extracted from the literature.
T7.4 and T7.5: Environmental costs and restrictions	
• CO_2 emission allowances • CO_2 equivalent factors for other polluting gases (if applicable) • Restriction on maximum allowed emission levels (if applicable, e.g. for SO_x and NO_x) • Acquisition and assembly cost of gas treatment technologies (e.g. for SO_x and NO_x) • Operation and maintenance costs of gas treatment technologies	• Literature • Existing European policies
T7.4 and T7.5: Miscellaneous data and information	
• Technology lifespan through the life cycle length. • Actualisation rate • Various growth rates (on energy prices, prices of raw materials, labour rates, etc)	EDF's and AMMR's estimations
T7.5: Electricity mix data	
• Modelled electricity mix in 2050	T7.2 EDF
T7.4 and T7.5 output data	
• Minimum ULCOWIN DSR cost • LCA and LCC results • Techno-economical analysis results	• Data provided by Quantis and N-Side • Minimum ULCOWIN DSR cost reused by EDF for T7.2

9 Presentation of WP7 deliverables

9.1 D7.2 Study report of the process integration with renewable energies

At the end of the integration study led by EDF, the following results will be delivered:

- The electricity price (€/MWh) based on EU Reference Scenario.
- The advantages of the ULCOWIN DSR contribution for the European power system and the development of RES (meet the flexibility needs while avoiding fixed and variable costs for the power system).
- Characterization of the ULCOWIN DSR contribution (frequency, duration, calendar, power called, cost).

Those results will be mentioned in deliverable D7.2 related to the study of process integration with RES.

Then, this deliverable will be completed with a sensitivity study as mentioned in 0 in order to evaluate the influence of adjustment variables on the previous results.

The scope of the study is Europe, but also with a focus in the main primary steel producing countries.

9.2 D7.3 Material and energy balances

Operation of the SIDERWIN pilot TRL6 during task 5.2 will provide mass and energy balance results. These results will be extrapolated to an industrial scale case with the same boundaries of a conventional steel plant. This extrapolation will include the steps not studied in this project but which are well described in engineering literature such as ultra-fine grinding and melting in the EAF.

This base case will be refined to include the influences of the electric interruption and iron oxide supply from alternative sources on the energy and mass balances of the ULCOWIN processing route.

The flow sheet of the ULCOWIN route will be described in detail to determine the type and size of the equipment. An estimation of the cost of these equipments will be derived to evaluate the overall capital cost of the processing route.

Comparisons will be drawn from existing processes such as electric scrap melting, chlor-alkali, aluminium, conventional electrowinning and conventional steel processes in order to crosscheck these cost estimates.

9.3 D7.4 Environmental life cycle assessment final report

Through the use of LCA, the environmental performance of the ULCOWIN technology will be quantitatively compared to a conventional steel production technology (Blast Furnace and Basic Oxygen Furnace) through several key indicators, especially GHG emissions, non-renewable primary energy use, water use and land use.

The material and energy requirement of a full scale ULCOWIN plant, extrapolated from the ULCOWIN pilot will be used as primary underlying data. The analysis will be performed for 1 t hot rolled coil as well as for the total European steel production with different levels of penetration of the ULCOWIN technology at the 2030 and 2050 time horizons. Scenarios for the ULCOWIN production route will be evaluated with an EU average electricity mix in 2030 and 2050, the latter based on the EU 2050 Roadmap and the modelling performed in T7.2.

This deliverable will analyse whether the ULCOWIN technology route can be a solution to reduce greenhouse gas emissions related to steel production in Europe and support the steel production sector to achieve a low carbon economy in Europe by 2050.

9.4 D7.5 Techno-economic assessment and life cycle costing final report

The purpose of the techno-economic analysis consists in evaluating the technical feasibility and the general profitability of the ULCOWIN technology, and compare it with the same metrics applied to the standard BF–BOF route (blast furnace – basic oxygen furnace).

The deliverable D7.5 will rely on a literature search (initiated in the framework of task 7.1) covering the most common methodologies for evaluating techno-economic performance of innovative industrial processes on one side, and on the other side the prospective studies defining scenarios on long term trends and evolution of the energy and raw materials markets.

This literature search is used as a basis for defining the main key performance indicator (KPI) to be used within the framework of the techno-economic analysis, which is the levelized manufacturing cost (as defined in D7.1). This is the minimal price at which finished product should be sold to exactly cover all costs for manufacturing the product, including the operational expenditures and capital expenditures recovery.

Deliverable D7.5 also includes the pursuance of the data collection process for gathering all inputs which will be necessary for defining the full market scenarios and evaluating the levelized manufacturing cost criteria. Scenario data will essentially be extracted from the literature and reference works such as Europe Reference Scenario published by the Commission. Technology-related data will mostly be provided from the results of other work packages (typically the mass and energy balance for the ULCOWIN pilot).

The next part of D7.5 then consists in the implementation of the model for computing techno-economic performance based on a set of inputs defined and validated with WP7 stakeholders. The full set of scenarios and the refined specification of ULCOWIN pilot will then be analysed and assessed at a final stage by running simulations based on this model, and results will eventually be compiled, summarized and interpreted.

10 Conclusions

Discussions among WP7 partners through physical or remote meetings lead to the definition of key elements to set the basis for the techno-economic and the environmental assessment. Three physical meetings took place on the 6 th December 2017, the 4th June 2018 (specifically between EDF and N-Side) and the 21st February 2019 in Paris ArcelorMittal offices in St Denis and have been complemented by email communications and phone calls. Deliverable D7.1 summarizes the outcome of these discussions. It defines the scope for each study (techno-economic, environmental, and process integration with RES), the expected deliverables of each task, the working methods, the input data in several categories, and the connection between the different studies. The common input data between all partners has been identified in order to ensure the consistency between the economic, environmental and energy scenarios.

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12 Annex

12.1 Description of impact categories

12.1.1 Environmental Footprint (EF) method for midpoint indicators

Climate change

Model: Bern model – Global Warming potentials (GWP) over a 100-year time horizon (IPCC 2013)

Unit: kg CO2-eq

Impact category that accounts for radiative forcing caused by greenhouse gas (GHG) emissions such as carbon dioxide (CO2), methane (CH4) or nitrous oxide (N2O). The capacity of a greenhouse gas to influence radiative forcing is expressed in terms of a reference substance (carbon dioxide equivalents) and considers a time horizon of 100 years following the guidelines from the Intergovernmental Panel on Climate Change (IPCC 2013). Radiative forcing is the mechanism responsible for global warming.

Ozone depletion

Model: EDIP model based on the ODPs of the WMO with infinite time horizon (WMO 1999)

Unit: kg CFC-11 eq

Impact category that accounts for the degradation of stratospheric ozone due to emissions of ozone-depleting substances, for example long-lived chlorine and bromine containing gases (e.g. CFCs, HCFCs, Halons). The emission factors are calculated using Ozone Depletion Potentials (ODP) reported by the World Meteorological Organization. The ODP is a relative measure for the potency of a substance to destroy the ozone layer. Stratospheric ozone filters out most of the sun's potentially harmful shortwave ultraviolet (UV) radiation. When this ozone becomes depleted, more UV rays reach the earth. Exposure to higher amounts of UV radiation can causes damages to human health such as skin cancer, cataract and weakened immune system. The impact metric is expressed in kg CFC-11-eq (CFC-11 to air equivalents).

Human toxicity, non- cancer effects

USEtox model (Rosenbaum et al. 2008)

Unit: CTUh

Impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to non-cancer effects that are not caused by particulate matter or ionizing radiation. The impact metric is expressed in CTUh (i.e. comparative toxic units for humans in terms of cases, the estimated increase in morbidity in the total human population).

Human toxicity, cancer effects

USEtox model (Rosenbaum et al. 2008)

Unit: CTUh

Impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to cancer. The impact metric is expressed in CTUh (i.e. comparative toxic units for humans in terms of cases, the estimated increase in morbidity in the total human population).

Particulate matter

Model: PM method recommended by UNEP (Fantke et al. 2015)

Unit: deaths per kg PM2.5-emitted

Sometimes named respiratory effects, respiratory inorganics or winter smog, this impact category measures the potential impact on human health (such as acute and chronic respiratory diseases and asthma attacks) caused by emissions of inorganic particles. It takes into account the adverse health effects on human health caused by emissions of Particulate Matter (PM) and its precursors (NOx, SOx, NH3) into the air. The impact metric is expressed in deaths per kg PM2.5-emitted (PM2.5 covers all particles < 2.5 μm).

Ionising radiation

Model: Human Health effect model (Dreicer et al. 1995)

Unit: kg U235-eq

Impact category that accounts for the adverse health effects on human health caused by the routine releases of radioactive material into air and water. The model describes the routine 14 atmospheric and liquid discharges in the French nuclear fuel cycle. The impact metric is expressed in kg U235-eq (Uranium 235 to air equivalents).

Photochemical ozone formation

Model: LOTOS-EUROS model (van Zelm et al. 2008)

Unit: kg NMVOC-eq

Impact category that accounts for the formation of ozone at the ground level of the troposphere caused by photochemical oxidation of Volatile Organic Compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NOx) and sunlight. High concentrations of ground-level tropospheric ozone damage vegetation, human respiratory tracts and manmade materials through reaction with organic materials. The impact metric is expressed in kg NMVOC-eq (non-methane volatile organic carbon to air equivalents).

Acidification

Model: Accumulated Exceedance model (Seppälä et al. 2006; Posch et al. 2008)

Unit: mol H+ -eq

Impact category that addresses impacts due to acidifying substances in the environment. Emissions of nitrogen oxides (NOx), ammonia (NH3) and sulphur oxides (SOx) lead to releases of hydrogen ions (H+) when the gases are mineralized. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in forest decline and lake acidification. The impact metric is expressed in mole H+-eq (hydrogen ions to soil and water equivalents).

Terrestrial eutrophication

Model: Accumulated Exceedance model (Seppälä et al. 2006; Posch et al. 2008)

Unit: mol N-eq

Impact category that addresses impacts from nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilized farmland which accelerate the growth of vegetation in soil. The degradation of organic material consumes oxygen resulting in oxygen deficiency. With respect to terrestrial eutrophication, only the concentration of nitrogen is the limiting factor and hence important. The impact metric is expressed in mole N-eq (nitrogen equivalents).

Freshwater eutrophication

Model: EUTREND model (Goedkoop et al. 2009)

Unit: kg P-eq

Impact category that addresses impacts from nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilized farmland which accelerate the growth of algae and other vegetation in freshwater. The degradation of organic material consumes oxygen resulting in oxygen deficiency. In freshwater environments, phosphorus is considered the limiting factor. The impact metric is expressed in kg P-eq (kg phosphorous to freshwater equivalents).

Marine eutrophication

Model: EUTREND model (Goedkoop et al. 2009)

Unit: kg N-eq

Impact category that addresses impacts from nutrients (mainly nitrogen and phosphorus) from sewage outfalls and fertilized farmland which accelerate the growth of algae and other vegetation in marine water. The degradation of organic material consumes oxygen resulting in oxygen deficiency. In marine environments, nitrate (NO3) is considered the limiting factor. The impact metric is expressed in kg N-eq (kg nitrogen to water equivalents).

Freshwater ecotoxicity

USEtox model (Rosenbaum et al. 2008)

Unit: CTUe

Impact category that addresses the toxic impacts on an ecosystem, which damage individual species and change the structure and function of the ecosystem. Ecotoxicity is a result of a variety of different toxicological mechanisms caused by the release of substances with a direct effect on the health of the ecosystem. The impact metric is expressed in CTUe (i.e. comparative toxic unit for ecosystems in terms of the estimated potentially affected fraction of species (PAF) integrated over volume and time, i.e. PAF*m3*y).

Resource use, minerals and metals

Model: CML 2002 model (Guinee 2002; van Oers et al. 2002)

Unit: kg Sb eq

Category that measures the potential impact on resource depletion from mineral and metals resource use. The emission factors are determined on an ultimate reserves and rate of de-accumulation approach. The impact metric is expressed in kg Sb-eq (kg antimony equivalents).

Resource use, energy carriers

Model: CML 2002 model (Guinee 2002; van Oers et al. 2002)

Unit: MJ

Category that measures the potential impact on non-renewable resource depletion from energy carriers (i.e., fossil fuels and uranium). The impact metric is expressed in MJ (megajoules).

Land use

Model: Soil quality index based on LANCA model (Beck et al. 2011)

Unit: points (dimensionless)

The LANCA® (Land Use Indicator Value Calculation in Life Cycle Assessment) model assesses the environmental impact from land occupation and land transformation through four indicators: biotic production, erosion resistance, mechanical filtration and groundwater replenishment. The European Commission Joint Research Centre (JRC) aggregated these into a single Soil Quality Index. The LANCA®

Water scarcity footprint

Model: AWARE 100 (Boulay et al. 2017)

Unit: m3 water deprived-eq

This impact indicator assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived. It is based on the AWARE 100 model, the recommended method from WULCA for water consumption impact assessment in LCA.

12.1.2 Endpoint indicators

Human health

Impact that can be caused by the release of substances that affect humans through acute toxicity, cancer-based toxicity, respiratory effects, increases in UV radiation, and other causes; an evaluation of the overall impact of a system on human health has been made following the human health end-point in the IMPACT 2002+ methodology, in which substances are weighted based on their abilities to cause each of a variety of damages to human health. These impacts are measured in units of disability-adjusted life years (DALY), which combine estimations of morbidity and mortality from a variety of causes.

Ecosystem quality

Impairment from the release of substances that cause acidification, eutrophication, toxicity to wildlife, land occupation, and a variety of other types of impact; an evaluation of the overall impact of a system on ecosystem quality has been made following the Ecosystem quality endpoint IMPACT 2002+ methodology, in which substances are weighted based on their ability to cause each of a variety of damages to wildlife species. These impacts are measured in units of potentially disappearing fractions (PDF), which relate to the likelihood of species loss.

12.2 Life cycle perception game

The Life Cycle Perception game developed by Quantis has been used to introduce LCA concepts to other consortium partners by discussing the environmental impact of steel as hot rolled coil produced through blast furnace followed by oxygen furnace.

Figure 12.1: Life cycle perception board game presented during the M6 steering committee meeting on April 19 2018

12.3 Input data for the process integration study with RES

12.3.1 Energy, transport and environment - Public data sources

- Energy mix, demand level, CO_2 emissions, etc. :
  - European commission, « EU Reference Scenario 2016 - Energy, Transport and GHG emissions trends to 2050 - Main results » : https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf

- Grid connections between European countries :
  - TYNDP 2016 https://www.entsoe.eu/publications/tyndp/tyndp-2016
  - e-Highway 2050: Results 2015 http://www.ehighway2050.eu/results/?tx_ttnews%5Bcat%5D=52&cHash=10890a2aacfb4d778fb5599f4940b240

- Electric Vehicles :
  - « Bilan Prévisionnel de l'équilibre offre-demande d'électricité en France », édition 2017 https://www.rte-france.com/sites/default/files/bp2017_complet_vf.pdf

  - TYNDP 2018 - Scenario Report - Main Report https://tyndp.entsoe.eu/maps-data/

- Fixed costs of electricity production :
  - « Bilan Prévisionnel de l'équilibre offre-demande d'électricité en France », édition 2017. https://www.rte-france.com/sites/default/files/bp2017_complet_vf.pdf

12.3.2 The European steel industry

- Steel production levels for all European countries and primary/secondary steel shares :
    - EUROFER fact and figures: http://www.eurofer.org/Facts%26Figures/Crude%20Steel%20Production/All%20Qualities.fhtml
    - WORLDSTEEL Statistical Yearbook: https://www.worldsteel.org/steel-by-topic/statistics/steel-statistical-yearbook.html
- The future of the European steel industry:
    - « A steel roadmap for a Low Carbon Europe 2050 », EUROFER, 2013
    - « Steel's contribution to a Low-Carbon Europe 2050, Technical and economic analysis of the sector's CO2 abatement potential », BCG/VDEH, 2013
    - IERO publications