Ref. Ares(2020)5121403 - 30/09/2020

PROJECT: SIDERWIN

Deliverable:

D7.4

Title:

Environmental life cycle assessment intermediary report

Date:	September 2020
Version:	1.0
Website:	N/A

Status

☒Final	
☐In Progress. Please explain:	☒ Iterative Process – This year's results have been 100% achieved. ☐ Delay – This year's results were not fully achieved.

Tracking Changes

Initial Version	N/A	N/A

Level of Dissemination

☐ Confidential

☒ Public

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Glossary

BF-BOF	Blast furnace – basic oxygen furnace
CAPEX	Capital Expenditure
CCS	Carbon Capture and Sequestration
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
IF	Induction Furnace
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

D7.4 is the fourth deliverable of WP7 and analyses whether the SIDERWIN 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.
This first version of D7.4 presents the results for a cradle-to-gate carbon footprint of steel produced with the SIDERWIN technology, based on pilot-scale data and the 2016 EU Reference scenario for electricity modelling.
The latter version of the assessment, which will be presented in the final D7.4 at M66, will have a broader scope, including the cradle-to-grave lifecycle of steel, a more sector-scale analysis, and indicators beyond GHG emissions.

The findings of this first assessment confirm the potential for carbon footprint reduction that resides in the SIDERWIN technology, ranging from 23% in the 2020 scenario, to 82% in a 2050 decarbonised electricity scenario.

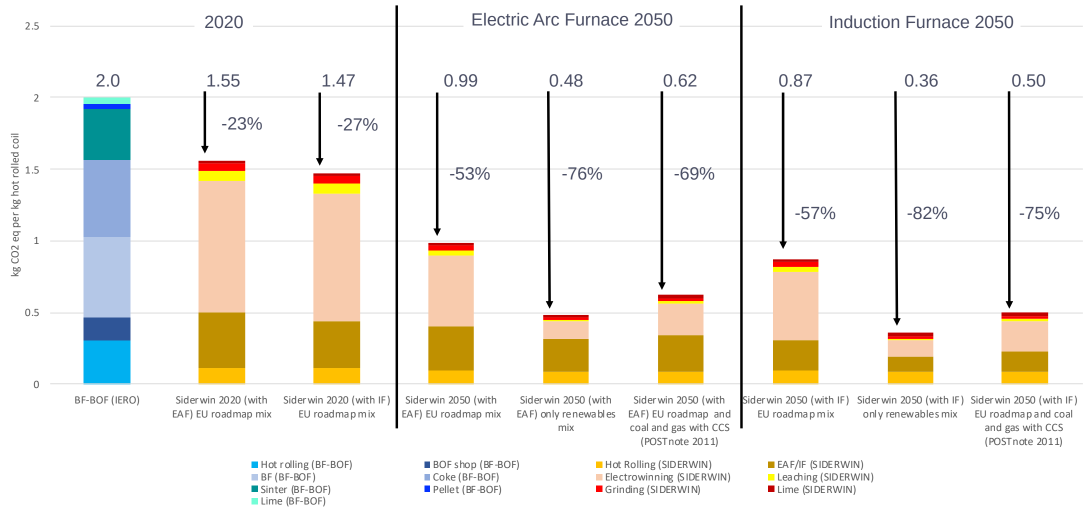

Figure 1.1: Carbon footprint of the SIDERWIN technology in several scenarios

The results' sensitivity to the electricity mix also emphasise the importance of the electricity mix modelling, especially for the 2050 scenarios, and for assessing the benefits of the penetration of SIDERWIN at a sectorial level in the final assessment.

2 Introduction

The European Commission has set 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 SIDERWIN 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.

The material and energy requirement of a full scale SIDERWIN plant, extrapolated from the SIDERWIN pilot have been used as primary underlying data. The present assessment was performed for 1 t hot rolled coil, in terms of carbon footprint, for different electricity mixes at the 2020 and 2050 horizons. The final 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 SIDERWIN technology at the 2020 and 2050 time horizons.
Scenarios for the SIDERWIN production route are evaluated with an EU average electricity mix in 2020 and 2050, the latter based on the EU 2050 Roadmap and the modelling performed in T7.2.

3 Goal and scope of the Life-Cycle 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 SIDERWIN 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

Until M36, the environmental study, which is presented in this report, is based on the first functional unit, the production of 1 t of mild steel. After M36, the assessment will be extended to both functional units, including the European total production

a.

b.

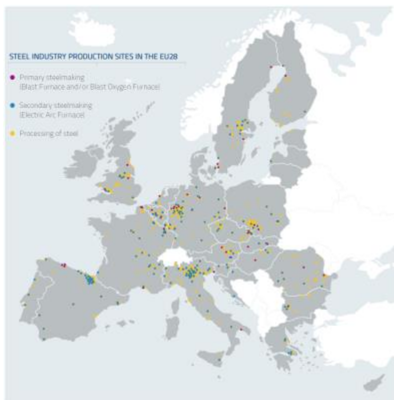

Figure 3.1: a. Steel hot rolled coil, b. European steel productions sites

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 environmental study, which is presented in this report, focuses 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).

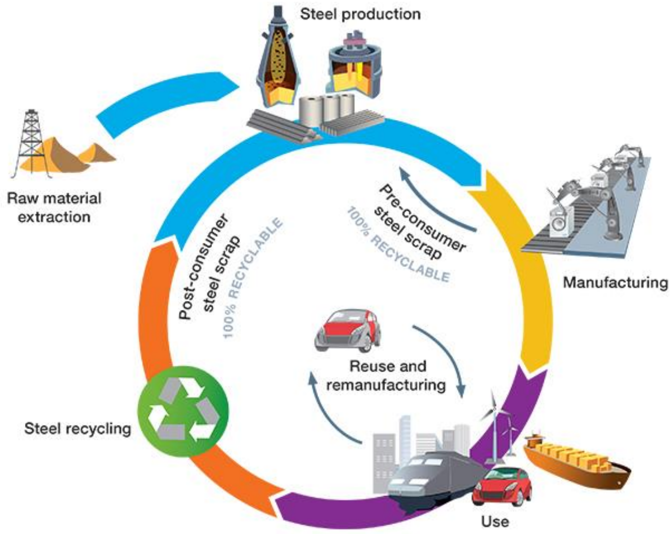

Figure 3.2: Cradle-to-grave life cycle system for steel, from Worldsteel 2015 Steel in the circular economy, a life cycle perspective

3.3 Reference technologies

The SIDERWIN technology performance was compared to key reference technologies to produce steel.

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

For comparison to the BF/BOF route, the SIDERWIN technology was considered as combined with both Electric Arc Furnace, and Induction Furnace.

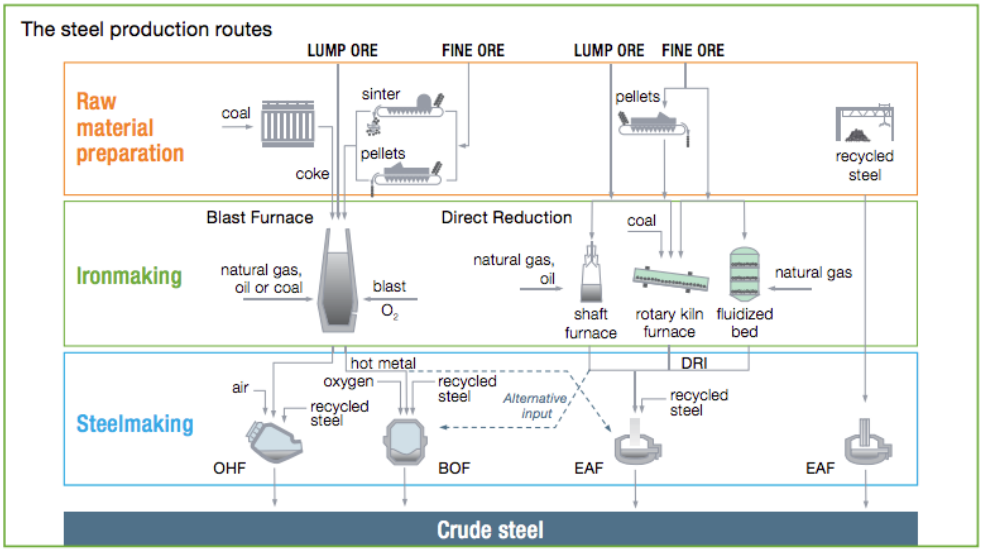

Figure 3.3: Steel production routes, from Worldsteel 2015 Steel in the circular economy, a life cycle perspective

3.4 Time horizon

The environmental studies assess both the current steel production as well as a future time horizon for which steel production with conventional technologies or the SIDERWIN technology will be assessed.

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

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

The 2050 model is be compared with the 2020 scenario with the European Commission emission targets for 2020 (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.

2020= beginning of the SIDERWIN industrial development (first plant).

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

3.5 Reference scenarios for RES

According to the previous part of this document, the environmental assessment requires a projection of the SIDERWIN industrial development on the horizon 2020 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.

SIDERWIN 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 SIDERWIN will set up.

In addition, because an electrolysis process can have a high Demand Side Response (DSR) potential, an SIDERWIN 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 SIDERWIN 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 SIDERWIN cost-effectiveness, specifically in terms of electricity prices and DSR incomes. Other external factors will influence the profitability of an SIDERWIN plant, for example the development of competitors on the DSR market.

Therefore, the environmental assessment requires to define a development scenario for the European power system on the horizon 2020 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 2020 and 2050.

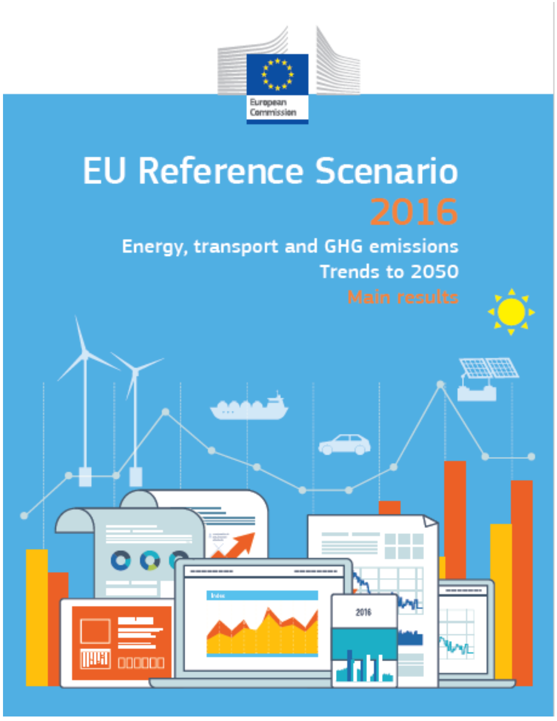

Figure 3.4: EU Reference Scenario 2016 - Energy, transport and GHG emissions – Trends to 2050

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 2020 of the EU Reference Scenario could also be taken into account in order to study the impact of the first SIDERWIN 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 Data sources

In order to assess the sustainability of the SIDERWIN steel production technology, the assessment requires input data for both the modelling of the steel production pathways, and the electricity production scenarios in 2050.

4.1 Data collection for steel production technologies

The input data for steel production pathways is based on both the previous IERO project, which modelled the SIDERWIN technology, specific data from ArcelorMittal, and literature data.

4.1.1 Data for BF / BOF and EAF – SIDERWIN Pathways

As described in deliverable 7.1, primary data has been collected from ArcelorMittal for the steel production with the SIDERWIN technology as well as reference technologies. Data from previous project IERO existed for both the BF/BOF route, and the Electrowinning/EAF route (see below).

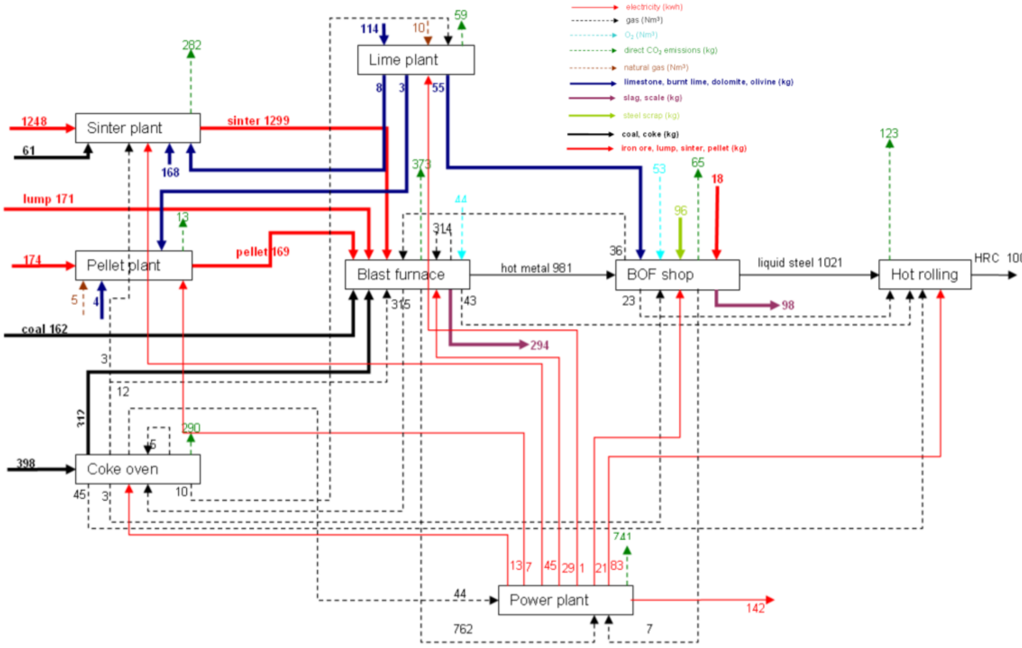

Figure 4.1: Flowchart for the BF / BOF steel production route

For the BF/BOF pathway, specific data was collected from ArcelorMittal plants, in an attempt to construct an average that would be more specific than the IERO data. After analyzing the data, it appeared that the variability from one plant to another (in terms of technology, on-site electricity production and auxiliary activities) was such that the sample considered was potentially biased and inconsistent in terms of mass balances. The IERO data, which corresponds to the average practice in Europe, and thus more representative and unbiased and was used in the present assessment

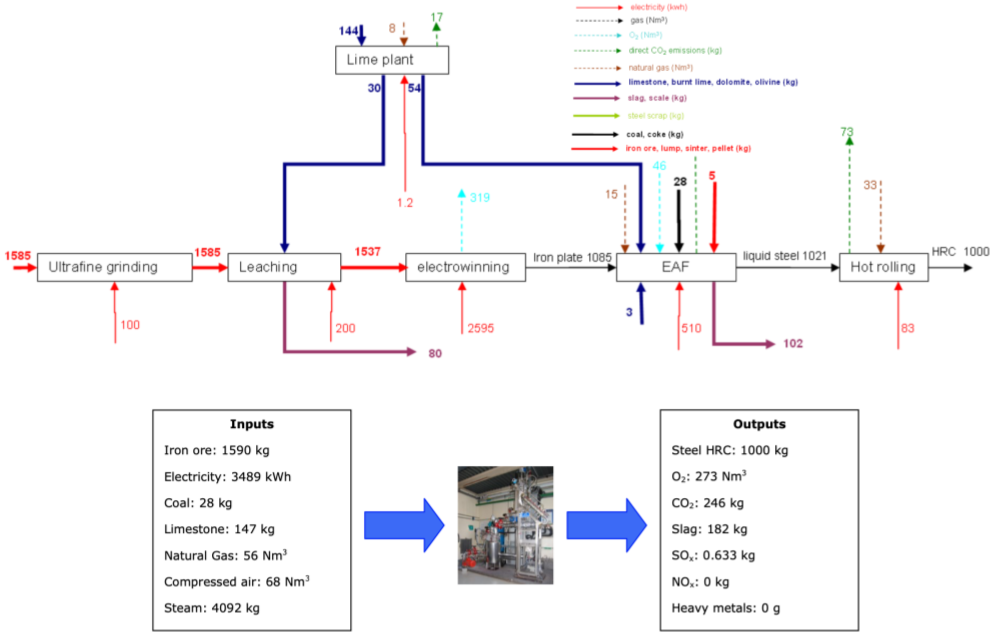

Figure 4.2: Flowchart for the EAF - SIDERWIN production route

4.1.2 Data for the SIDERWIN/IF pathway

In addition to the assessment of the SIDERWIN/EAF route, the possibility of combining the SIDERWIN process with the induction furnace technology was identified as an improvement.

The data used to model the induction furnace was provided by ArcelorMittal, based on an article of Foundry Management and Technology magazine (see data table below). This inventory data was used to model the steel melting, while the rest of the pathway is considered identical to the EAF pathway.

Table 4.1: Data table for Induction Furnace Life-Cycle Inventory

	One 100 T EAF + LF Systems (120 MT/Hr)	Three 40 T IF Systems (120 MT/Hr)
Power Usage Melting	400 kWh/T	600 kWh/T
Auxiliary Power Usage	80 kWh/T	80 kWh/T
Melting, Oxygen Usage36 Nm3/T	---	
Additional Oxygen	4 Nm^3/T	8 Nm^3/T
Natural Gas	12 Nm^3/T	4 Nm^3/T
Electrodes	1.6 Kg/T	---
Fluxes	60 Kg/T	---
Coke	30 Kg/T	1Kg/T
Refractories	10Kg/T ($6.00/T)	20 Kg/T ($2.00/T)
Alloys	14 Kg/T	13 Kg/T
Maintenance	$5.00/T	$10.00/T
Water	1 m^3/T	0.5 m^3/T
Misc. Consumables	$1.50/T	$1.50/T
Misc. Expenses	$0.50/T	$0.50/T
Payroll (excludes scrap processing)	1.5 Set	6 Sets
Yield (Scrap/Billet)	89%	95%

(source: Foundry Management and Technology magazine)

4.1.3 Data refinements and improvements

The SIDERWIN inventory data is to be refined by ArcelorMittal in the context of Task 7.3, as they develop improvements for the pathway (low-carbon coke production routes, optimization of slag management).

The modelling of slags and co-products will also be refined by an economic allocation based on the economic data available. For now, they are modelled as waste, which means their environmental burden allocated to steel, instead of a product flow with potential value and use.

Concerning the Induction Furnace inventory, due to the limited transparency of the data, this is considered a preliminary data collection, to be refined after M36 by a further data collection, based on literature and discussions with induction furnace specialists, notably within ArcelorMittal.

4.2 European power system modelling

4.2.1 Scenarios for the average European electricity mix

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

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.

The average electricity mix for Europe in 2020 was built using the EU Reference Scenario from 2016 (see Figure 4.3: Electricity mix for 2020 and 2050

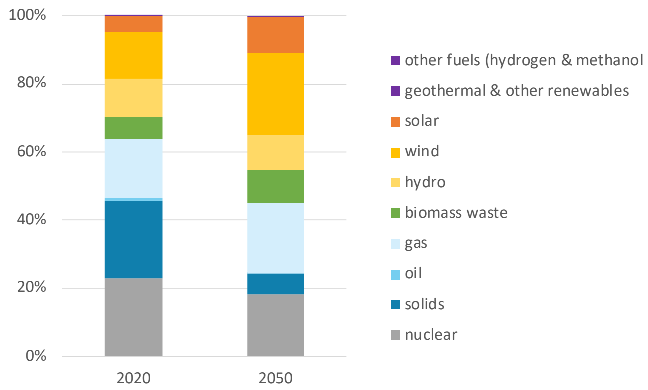

Figure 4.3: Electricity mix for 2020 and 2050

Source: EU Reference Scenarios 2016

Several scenarios were considered for electricity mixes in 2050:

- A scenario following the EU Reference Scenario
- A scenario following the EU Reference Scenario, in which coal and gas are combined with Carbon Capture and Sequestration (CCS), with emission factors for coal and gas with CCS extracted from the Postnote[1] publication
- A scenario with 100% renewables, with the renewable mix based on the EU Reference Scenario

In a preliminary approach, each electricity source emission factor was modelled using a dataset from ecoinvent, representing the practices of a given country, which is either leading in Europe for that electricity source, or conservative.

The four scenarios are summed up in the following table, which also presents the emission factors and the data used for the modelling of each electricity production

[1] POSTNOTE 383 (June 2011, Carbon Footprint of Electricity Generation), drafted by the UK Parliamentary Office of Science and Technology.

source. Figure 4.4: Carbon footprint of the different electricity mixes presents the carbon footprint of the different electricity mixes.

Table 4.2: Presentation of electricity mix scenarios

Electricity source	2020	2050	2050 with CCS	2050 100% ENR	kg CO2-eq/kWh	Data source
Nuclear	23%	18%	18%	0%	0.011	ecoinvent, French nuclear production
solids (coal)	23%	6%	0%	0%	1.09	ecoinvent, German hard coal electricity production
coal with CCS	0%	0%	6%	0%	0.200	Postnote
Oil	1%	0%	0%	0%	0.436	ecoinvent, French electricity oil production
Gas	17%	21%	0%	0%	0.958	ecoinvent, German CCGT production
gas with CCS	0%	0%	21%	0%	0.200	Postnote
biomass waste	6%	10%	10%	12%	0	ecoinvent, German waste incineration
hydraulic	11%	10%	10%	12%	0.051	ecoinvent, Spanish hydraulic electricity production
Wind	14%	24%	24%	29%	0.019	ecoinvent, danish wind electricity production
Solar	5%	11%	11%	13%	0.118	ecoinvent, german solar electricity production
geothermal & other renewables	0%	0%	0%	0%	0.079	ecoinvent, german geothermal

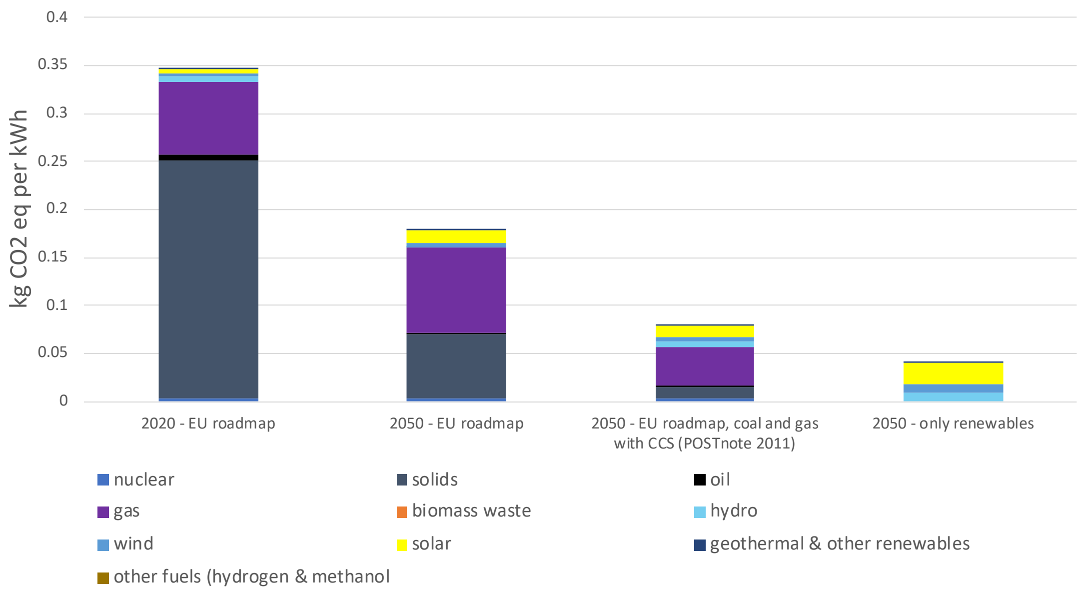

Figure 4.4: Carbon footprint of the different electricity mixes

4.2.2 Data refinements and improvements

The approach for modelling each electricity source is preliminary. The next iteration of the model will rely on a weighted average of the European production for each electricity source, based on EUROSTAT data for electricity production.

The modelling of coal and gas with CCS is also to be refined, as well as the Renewables scenarios.

In the final assessment, the whole European mix will be assessed at a global level in 2050, requiring additional data from EDF, especially regarding the integration of the flexibility and additional demand brought by the SIDERWIN technology.

5 Methodology for the environmental assessment

5.1 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 probable emissions 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 SIDERWIN technology can be quantitatively compared to a conventional steel production technology through several key indicators.

In particular, the carbon footprint of the SIDERWIN 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 SIDERWIN 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.

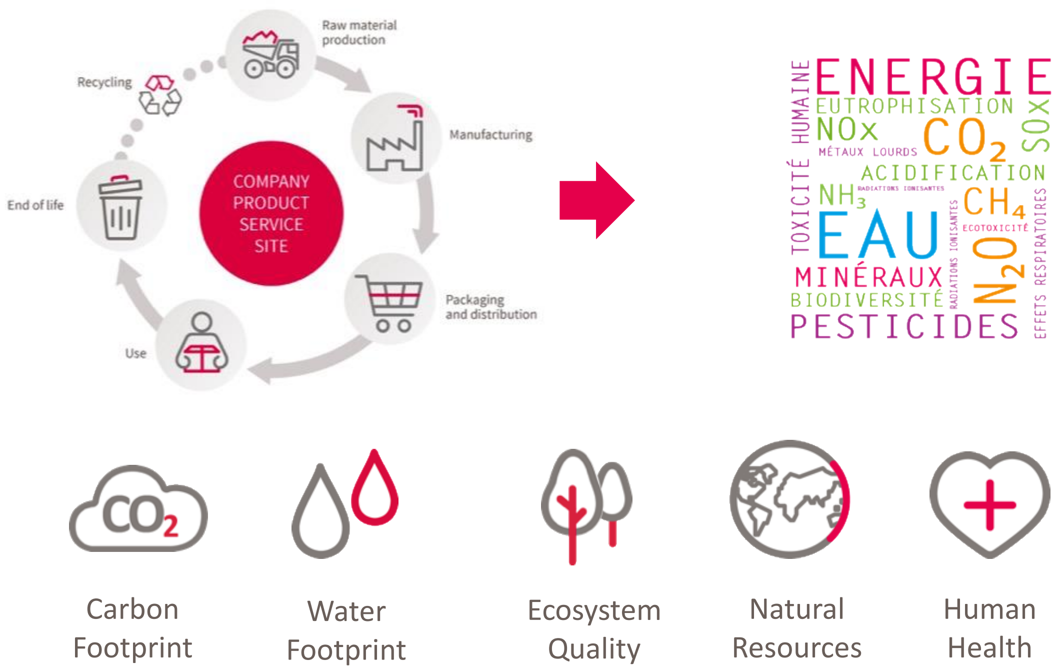

Figure 5.1: Life Cycle Assessment framework, from product life cycle inventory to environmental indicators

5.2 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.

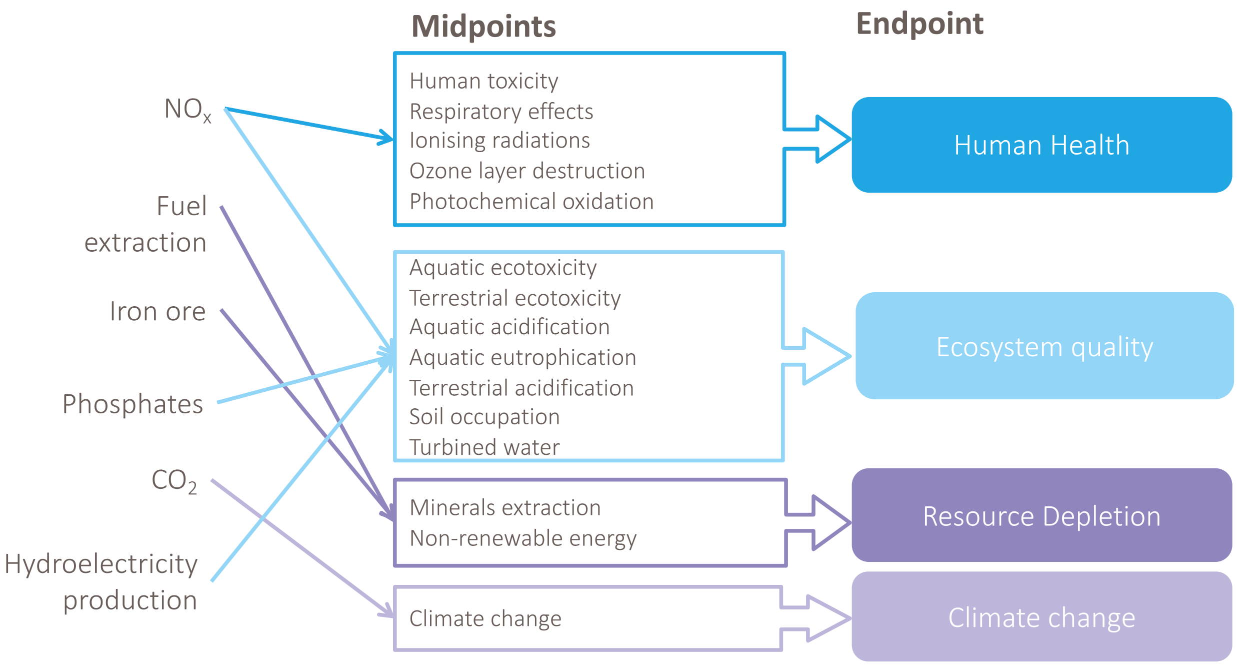

Figure 5.2: Impact assessment framework

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 analysed 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 5.1 describes the models used for each of the 16 indicators that will be considered in the environmental study.

Table 5.1: 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 9.1.

In the present assessment, we focus on GHG emissions. In the final assessment, 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.

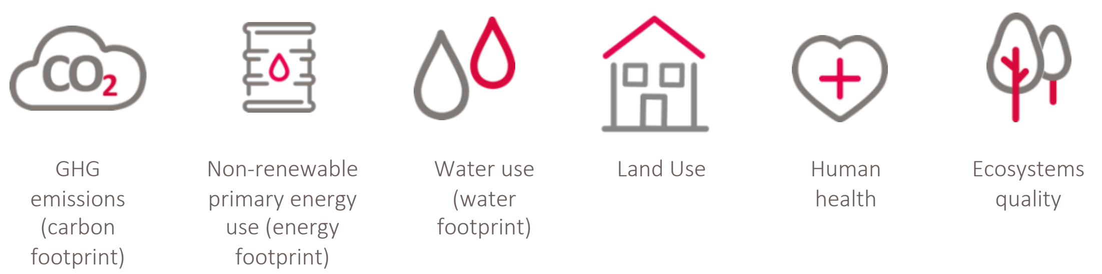

Figure 5.3: Key indicators assessed in the environmental study

6 Results

6.1 SIDERWIN vs. to BF-BOF, in 2020 and 2050

The results for Global Warming Potential (GWP 100a) for the SIDERWIN technology compared to BF-BOF are presented below, for the EAF and IF routes in the 2020 scenario, and for EAF route in the 2050 scenario.

For the reference BF-BOF route, the main contributing step of the route is the Blast Furnace (28%) and coke production (27%), followed by sinter (18%). 65% of the footprint is due to direct emissions from combustion, the remainder stemming from the value chain of the materials consumed.

For SIDERWIN technology routes, the main contributing step for both routes and both electricity mix scenarios are electrowinning (59% of the footprint for EAF in 2020), followed by the furnace (25% for EAF in 2020).

It should be noted that the major contributor to the footprint of the SIDERWIN technology is the electricity consumption: it represents 61% of the footprint for EAF in 2020, 68% for IF in 2020. In the 2050 scenario for EAF, this share is down to 45%.

Compared to the reference BF/BOF route, the total Global Warming impact of the SIDERWIN-EAF route in the 2020 scenario is 16% lower (1.55 kg CO_2-eq per kg of hot rolled coil, versus 2.02 kg CO_2-eq per kg of hot rolled coil). Those results validate the potential for reducing the footprint of steel production through electrification.

The results for the SIDERWIN/IF route allow for further reductions (-27% compared to BF/BOF, and -20% compared to EAF), outlining the induction furnace as an improvement for the SIDERWIN steel production route.

The SIDERWIN/EAF in the 2050 scenario (-51% compared to BF/BOF) show how the benefit of the SIDERWIN technology can be further leveraged by a cleaner electricity mix.

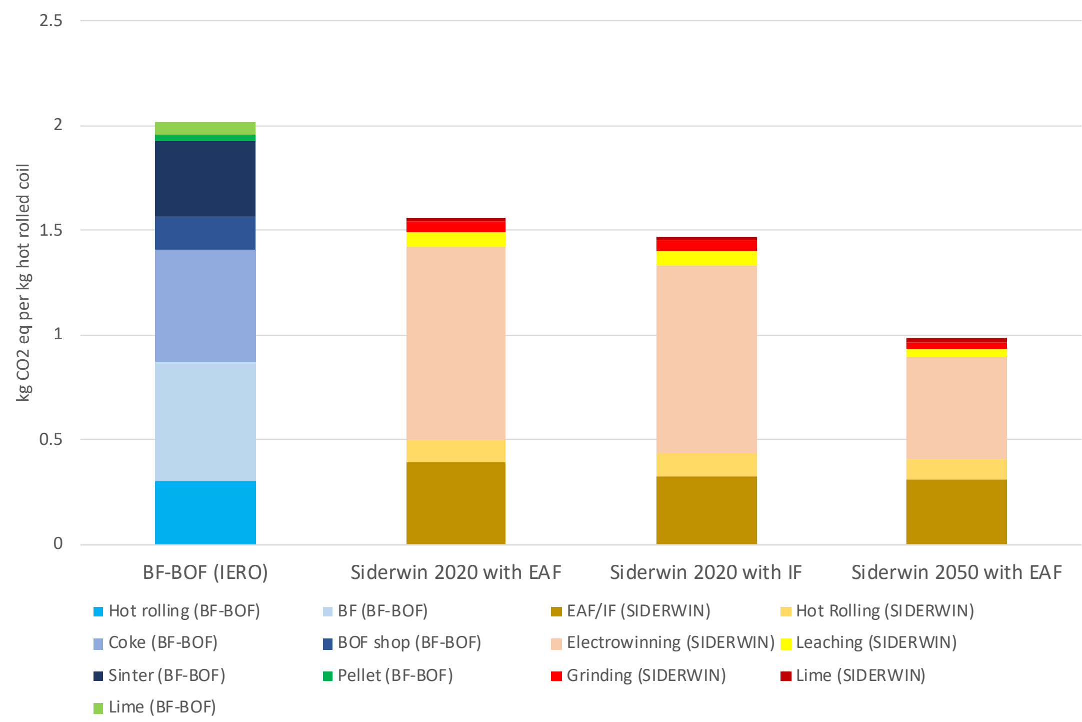

Figure 6.1: Results for the carbon footprint of SIDERWIN routes vs. BF/BOF

6.2 Results for various electricity scenarios

To explore further the sensitivity of the gains brought by the SIDERWIN technology in terms of carbon footprint, several scenarios for electricity mixes (presented in section 4.2) have been explored.

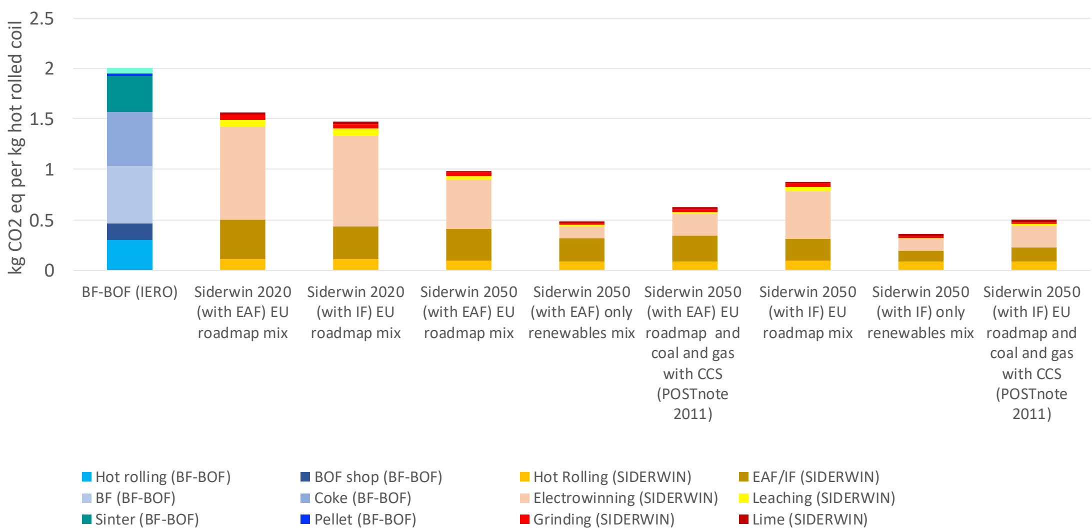

Figure 6.2: Results for the carbon footprint of SIDERWIN in the different electricity mix scenarios

As detailed in the previous subsection, in the 2050 EU Reference Scenario, the carbon footprint reduction compared to BF/BOF reaches 51% for SIDERWIN/EAF, and 57% for SIDERWIN/IF.

In the 2050 scenario with coal and gas with CCS, the reduction is 69% for SIDERWIN/EAF and 75% for SIDERWIN/IF. The reduction potential is the greatest in the 2050 Renewable mix scenario: 76% for SIDERWIN/EAF and 82% for SIDERWIN/IF.

This assessment on electricity mix scenarios shows that in every scenario assessed, the SIDERWIN technology allows for carbon footprint reductions compared to the traditional BF/BOF route, and that this reduction can reach 82% with an extreme low-carbon electricity mix.

7 Conclusions and next steps

This assessment establishes the strong potential for reducing emissions of the steel sector through electrification, using the SIDERWIN technology, with a reduction of 16% of the carbon footprint of steel coil in the most conservative, short term scenario, and an 82% reduction potential for SIDERWIN coupled with Induction Furnace in a decarbonised electricity mix.

The sensitivity of the results to the electricity mix stresses the importance of an accurate modelling of the electricity mix scenarios, especially at the 2050 horizon and for assessing sector and region-scale gains.

In the final assessment of task 7.4, the source data for electricity and steel production will have been refined, in the context of task 7.2 and 7.3, allowing for a more precise modelling. The assessment will also go beyond carbon footprint, including several other indicators, and including the rest of the life cycle of steel, beyond cradle-to-gate, and explore the consequences of the SIDERWIN technology at the level of the European electricity mix and the steel industry at large.

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9 Annex

9.1 Description of impact categories

9.1.1 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.

9.1.2 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.

9.2 Input data for the process integration study with RES

9.2.1 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

- Carbon capture and sequestration :
    - POSTNOTE 383 (June 2011, Carbon Footprint of Electricity Generation), drafted by the UK Parliamentary Office of Science and Technology.

9.2.2 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
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