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Issues Paper about How to Design Climate Bonds for the Steel and Selected Non-Ferrous Metals Sectors

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IMPRESSUM

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Abbreviations

2DS	2°C scenario
B2DS	Beyond 2°C scenario
BAT	Best available technology
BF	Blast furnace
BOF	Basic oxygen furnace
CBI	Climate Bonds Initiative
CCS	Carbon capture and storage
CCU	Carbon capture and usage
CDP	Carbon Disclosure Project
CHP	Combined heat and power
CO_2e	CO_2-equivalent
DRI	Direct reduced iron
EAF	Electric arc furnace
EC	European Commission
EJ	Exajoule
ESG	Environmental, social and economic
ETP	Energy Technology Perspectives
GEVA	Greenhouse Gas per Value Added
GHG	Greenhouse gases
GJ	Gigajoule
GRI	Global Reporting Initiative
GSSB	Global Sustainability Standards Board
H-H	Hall-Héroult Process
IAI	International Aluminium Institute
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISCG	International Copper Study Group
JRC	Joint Research Centre
MWh	Megawatt hour
NDC	Nationally determined contribution
PFC	Perfluorocarbons
RTS	Reference Technology Scenario
SASB	Sustainability Accounting Standards Board
SBN	Sustainable Banking Network
SBT	Science-based target
SDA	Sectoral Decarbonization Approach
SDG	Sustainable Development Goal

TCFD	Task Force on Climate-related Financial Disclosures
TEG	EU Technical Expert Group on Sustainable Finance
TRL	Technological readiness level
TWh	Terawatt hours

Executive Summary

Basic materials production is responsible for 25% of global greenhouse gas (GHG) emissions. However, both, mitigation efforts and results, are limited. While business-as-usual investments are declining, due to concerns about stranded assets and global over-supply of some materials like steel, the policy framework is insufficient for new low-carbon innovation and investments. To catalyse investments into low-carbon innovation and decarbonize the basic materials sector it is necessary to:

- Develop a shared understanding of development perspectives, including new technologies, materials and practices.
- Identify conducive conditions for climate-friendly innovations and investments.
- Explore options for refinement and use of existing and additional policy and market instruments.
- Discuss opportunities and challenges related to implementing such instruments.

Against this background, this issues paper discusses key elements that need to be considered for climate bonds or green bonds to play a role in financing decarbonisation in the aluminium and steel sector and to the extent that the relevant information was available, also the copper sector.

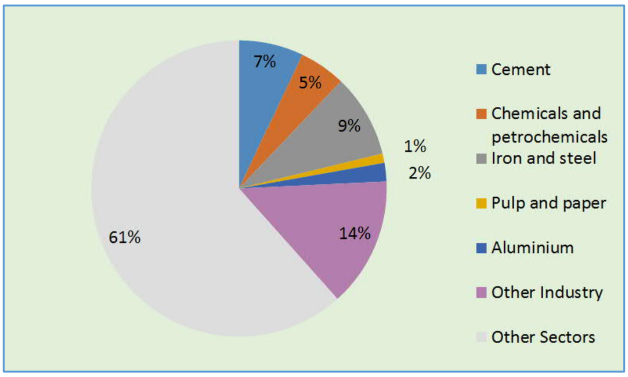


Figure E-1: Share of basic materials in global CO_2 emissions (Neuhoff et al., 2018 based on IEA ETP (2017))

What are the decarbonisation options in these sectors?

GHG emission reduction opportunities in the basic materials sectors can broadly be divided into five major groups of mitigation options for basic materials to achieve the 2050 objective:

- Best available technology (BAT)/Efficiency improvements of existing processes
- Recycling and re-use
- Material efficiency and substitution
- New clean production processes
- Green electricity/ fuel switch/ heat recovery from combined heat&power technology (CHP)

The paper discusses specific options for steel, aluminium and copper for all five categories.

Some important issues and questions emerge from the review of mitigation options:

- A wide range of mitigation options will be required alongside each other to tackle the required emission reduction challenge, but not all are compatible with the long-term decarbonisation targets. Investments in capital stock with 30-40 years life-cycle risk lock-in if the achieved emission reductions are not substantial enough. Against this backdrop, should investments in improving process efficiency or particularly efficient new installations qualify for green bonds issuance? Important to consider lock-in risks, going beyond BAT and improving efficiency above inherent improvements related to regular refurbishment cycles.

- Carbon neutral power supply plays a key role for important decarbonisation routes, also and in particular for the steel, aluminium and copper sectors. But here it is key to account for leakage and ensure additionality. Otherwise no net-carbon reducing effect can be secured.
- Climate friendly materials: Could a climate bond be linked to established materials, new process or new materials? Would only truly new materials qualify for green bond issuance?
- Financing circularity: What are sufficiently ambitious levels of improvements and how could new business models and practices be linked to bond issuance?

The role of scenarios

Emission scenarios are constructed to define how GHG emissions evolve over time, in relation to the carbon budget corresponding with international climate targets and agreements. The so-called Sectoral Decarbonization Approach (SDA) breaks down the global carbon budget into sectoral budgets that define carbon emission pathways for selected time periods. At company level, a target is considered science-based if it is designed to keep the GHG emissions of a specific company aligned with the global or corresponding sectoral carbon budget (SBTi, 2019).

The International Energy Agency (IEA) provides sectoral carbon budget scenarios for the steel and aluminium sector (not for copper). The corresponding benchmarks for evaluating corporate performance are sensitive to assumptions, and choices about the allocation of the available emissions (budget) to each sector are characterised by significant uncertainties. Yet, the SDA is easy to apply, it is transparent, widely used and suitable for comparing and benchmarking firms.

Scenarios are used to determine the mitigation efforts required by the sectors and ultimately, by the corresponding firms. Yet, due to different modelling approaches, the scenarios used in different studies are difficult to compare and there may be difficulties when translating the findings to the firm level. The major advantage of scenarios which integrate technology options and price changes is, however, that they give very detailed insights into the potential of individual technologies. At the same time, the level of detail requires a number of estimates and assumptions, which makes it very difficult to compare results across these technology mix and cost scenarios and for different technology mixes. This approach is furthermore highly sensitive to assumptions about the speed and extent of future technological innovations. A strength of it is that it indicates which technologies are pivotal for the decarbonisation of the sectors.

Companies´ Target Setting: absolute or intensity target, target Boundaries and target reliability

Based on the discussion of scenarios and emission pathways, the report also assesses how metrics, benchmarks and technical eligibility criteria can be derived to evaluate individual firms and assets and corporate low-carbon transition strategies. Subject to the approach and the nature of the science-based reduction target, emission pathways for companies can be identified. The company´s target, which is compared to a benchmark by means of the contraction or convergence method and different science-based target methods, can either be an absolute or an intensity target.

For defining a target, boundaries, like the emission scopes, the greenhouse gases and the geographical operations, must be set. The Science Based Target Initiative suggests the inclusion of emissions of scope 1 and 2, i.e. emissions from company´s direct operations and in relation to electricity consumption; and a target for scope 3 emissions if these indirect emissions cover over 40% of the total emissions (SBTi, 2019). In the Science-Based Target approach, assets are evaluated based on expected pathways. To derive a future emission pathway of a company, emission and production targets must be considered. To classify a corresponding corporate bond as "green", the firm's carbon management quality and target reliability must be ensured.

Ideas for basic typologies for climate bonds relating to basic materials production

Climate bonds can build on specific technologies, taking into account how they align with long-term decarbonisation pathways. Alternatively, they could rely on company-level assessments.

Technology-based: technology portfolios from roadmaps, technology requirements from 1.5/2C pathways

A project based green bond could be based on an assessment of the specific technology. GHG reduction options for basic material production can be classified into three groups:

1. Min-10 – Minimum of 10% GHG reduction: Improvements that can be achieved through available technology – typically (for example for the purpose of allocating free allowances to energy intensive installations under the EU Emissions Trading Scheme) defined by the 10% most efficient/least GHG intensive installations
2. Min-30 – Minimum of 30% GHG reduction: Measures that achieve significant improvements above the current BAT benchmark
3. NCN – Net carbon neutral: Deep decarbonisation of the production process

Ultimately, and in order to achieve net carbon neutrality, in line with global climate targets and aligned emission pathways, by 2050, only processes of the third category are suitable. If improvements of a process step deliver large-scale emission reductions at the level of that process step only, while the final material still remains relatively carbon intensive due to emissions in further process steps, it may be necessary to asses overall performance across all process steps (and emission scopes) when evaluating the eligibility of a corporate/project for green bond use of proceeds status.

Alternative specifications that would allow improvements at lower levels of emission reduction to qualify for green bonds entail two potentially significant risks:

- Lock-in of technology development with technologies that are not suitable to deliver emission reductions to the degree required for preventing catastrophic climatic change.
- Stranded asset risks for investors (as discussed for the case of critical-coal projects under the Clean Development Mechanism), if the market penetration of net carbon neutral

technologies shifts the emission baseline below the emission level of installations optimised at BAT-level.

Therefore, the paper suggests for an initial concept of green/climate bonds in the materials sectors to focus eligibility on technologies of the third category above.

Corporate level: Science-based target appraisal, corporate strategy and the Sectoral Decarbonisation Approach (SDA)

Apart from technology portfolios as described in the previous section, the evaluation of a firm against science based targets and corresponding scenarios and carbon budgets, needs to reflect a set of key issues regarding management quality, reporting requirements and scenario compatibility in its corporate strategy in order to qualify for a green bond:

Management quality

The Transition Pathway Initiative (TPI) has developed a method to capture the elements of governance, strategy and risk management, so that a company's management quality can be assessed. TPI highlights that a company's carbon performance is not necessarily indicative of a company's performance in the three management-related disclosure elements. For example, a company could have a carbon performance in line with the sectoral benchmark, but that does not imply that the quality of its management around carbon-related issues is compliant to standards such as the Task Force on Climate-related Financial Disclosures (TCFD). According to TPI, a poor management performance could imply that the company will not be able to stay compliant.

Required Disclosures

To ensure transparency for both scenario compatibility and management quality, a company is required to report and disclose elements important for assessing its carbon performance. There are multiple reporting frameworks and this paper includes a detailed discussion (in Annex II).

For this study, especially the GRI standards on emissions (GRI 305), renewable energy (GRI 103, 302-1) and energy efficiency (GRI 103, 302-3, 302-4) are relevant. Similarly to the TCFD framework, the GRI specifically highlights disclosure of a company's management approach (GRI 103). The GRI standards for management disclosures are very extensive, they for example also include requirements for companies to report on the evaluation procedure of their management approach (GRI, 2018).

Scenario compatibility

For assessing a company's scenario compatibility, its emission intensity pathway, depending on current emissions and emission targets, is compared to its sector´s emission intensity pathway (see for example TPI). A company should be familiar with the sector specific benchmarks and set out a vision as to how it is planning to reduce the emission intensity of their production output in the long run as part of their business strategy and financial planning. Targets should be ambitious, realistic and measurable. As each company has a unique set-up and market position, an appropriate technology roadmap needs to indicate how the firm is planning to reach its targets. It is crucial that the technology roadmap includes a firm's financial plans regarding technology investments. As discussed in detail in this paper, implementing current (so called) best available technologies (BAT) is not sufficient to decarbonize the materials sectors. Accordingly, a firm should also set plans regarding investments in R&D and net-carbon neutral technologies and show in how far its mitigation efforts go significantly above BAT and efficiency improvements related to regular, cyclical technology up-dates.

A critical discussion of reference benchmarks and how to link them with specific decarbonisation plans and measures of a company

Technology portfolios can be assessed with intensity benchmarks. For intensity-based benchmarks, the weighted emission intensity (as a function of emission intensities of individual technologies and emission share) can be compared to sectoral emission intensity. For example, the literature expresses efficiency gains in percentage per production step, costs savings and reductions of energy per unit of activity. With this information, a company could assess how a new technology contributes to its emission intensity reduction target and with which benchmark (or level of ambition) the resulting technology mix is in compliance.

Limitations of applying the scenario derived benchmarks to individual technologies and production pathways

It is important to note that the existing scenario derived benchmark values currently only reflect aggregate values for:

- secondary and primary aluminium. As secondary aluminium is much less energy intensive than primary aluminium, the future share of secondary aluminium has a crucial influence on the aggregate benchmark values.
- existing and new facilities. The benchmark therefore reflects the share of primary production facilities that have been upgraded.

The average carbon intensity of a benchmark does not directly inform the evaluation of a specific investment. For example, an improvement of the average carbon intensity by 33% can be achieved either with a 33% improvement of all existing facilities, or with a 100% improvement of 33% of the production capacity of a firm. It is likely that only the latter approach will be compatible with a transition to net carbon neutrality. Therefore, it is crucially important that firms not only report their carbon intensity target for 2030, but in addition either:

- report the share of carbon neutral production in total production; or
- demonstrate otherwise the alignment of the measures/investments targeting emission reduction (and eventual “compliance” with the various sector pathways and scenarios) by 2030 with a credible path towards net carbon neutrality in 2050.

However, TPI and IEA benchmark values are only available until 2030. As investment decisions into new technologies have a longer lifetime, this is a relatively short timeframe which makes the benchmark values less relevant or even misleading when using them to determine technologies’ or projects’ “Paris compatibility”. 2050 benchmarks, while sparsely available, are more relevant and need to be developed further for the different sectors. Moreover, it will be important to develop disaggregated benchmarks for primary and secondary production and for existing and new facilities.

1 Introduction

Background

Basic materials production is responsible for 25% of global greenhouse gas (GHG) emissions. However, both efforts and results on mitigation are limited. While business-as-usual investments are declining, due to concerns about stranded assets and global over-supply of some materials like steel, the policy framework is insufficient for new low-carbon innovation and investments.

To catalyse investments into low-carbon innovation and decarbonize the basic materials sector it is necessary to:

- Develop a shared understanding of development perspectives, including new technologies, materials and practices.
- Identify conducive conditions for climate-friendly innovations and investments.
- Explore options for refinement and use of existing and additional policy and market instruments (national and European).
- Discuss opportunities and challenges implementing such instruments.

Against this background, this issues paper discusses key elements that need to be considered for climate bonds or green bonds to play a role in financing decarbonisation in the materials sectors.

Objective

The Climate Bonds Initiative (CBI) seeks to inform the process of developing climate bonds for the materials sectors by commissioning this issues paper produced by the German Institute for Economic Research (DIW). This issues paper is not meant to provide answers to all 2-degrees pathways related questions for the sectors at hand. Neither does it pre-empt any potential future development of criteria under CBI's Standard & Certification Scheme. The objective of this issues paper is to provide reasonable assurance that crucial climate-relevant aspects are in scope. It flags the issues corporates would have to address, and it points toward potential solutions.

2 Characterisation of the sectors' climate relevance and key transition features

2.1 How "climate-relevant" are the materials sectors? Emissions shares and contribution to climate change

Globally, the basic material sectors contribute 25% to total greenhouse gas emissions, as shown in Figure 1. Of this, the iron and steel sector is the largest emitter, followed by the cement and the chemicals and petrochemicals sectors. Aluminium and pulp and paper constitute smaller shares, yet still make up more emissions than for example the entire aviation industry.

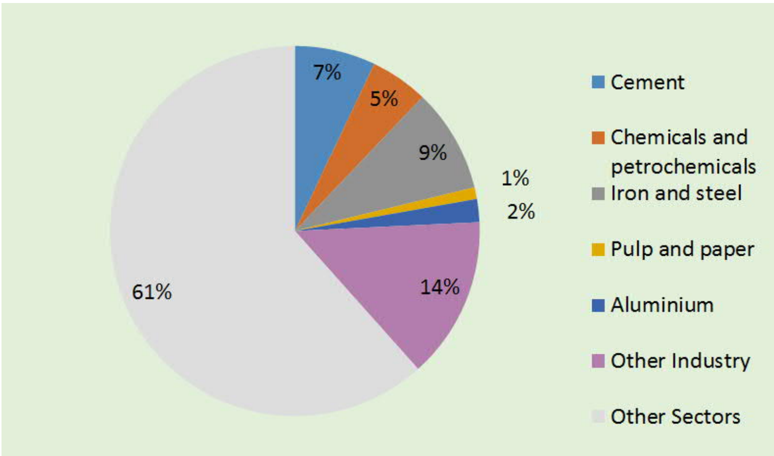


Figure 1: Percentage contribution of various basic materials in global CO_2 emissions (Neuhoff et al., 2018 based on IEA ETP (2017))

In the long run, global economic growth fuels increasing demand for steel and aluminium and global demand is expected to peak the earliest in 2050. With no readily available low-carbon competition for these highly energy-intensive materials, (some of which also play an important role in the manufacturing of low-carbon technologies, such as wind turbines) identifying and scaling up new innovative production processes and technologies is fundamental to reducing global greenhouse gas emissions. The magnitude of this challenge indicates that this transformation requires substantial investments and can infer substantial costs.

Although the main focus of this report is on the greenhouse gas emissions from the steel, aluminium and copper production, a consideration of up-stream emissions is important (conceivably even more so for non-carbon issues). To allow the reader to develop an order of magnitude idea about up-stream emissions, GHG emissions and abatement options from mining are discussed briefly in Box 1 at the end of section 2.

2.1.1 Steel

Iron and steel products can be classified into three main categories: crude steel, semi-finished products and finished products. Crude steel can be either sold or can be further processed to semi-finished and finished products. The conventional production methods are primary and secondary steel making. Primary steel can be produced in blast furnaces (BF) and basic oxygen furnaces (BOF), the CO-BF-BOF production route, and by smelting reduction (SR-BOF). A third route is using direct reduced iron (DRI), which is not largely applied. The production of primary steel making consists of the raw material preparation, iron and steel making. Secondary steel production requires less energy and electricity as the main energy carrier. Scrap iron is melted and refined in Electric Arc Furnaces (EAF) utilising high amounts of electric current. Finished steel products can be classified into flat and long finished steel products. If electrical energy is obtained by renewable sources, secondary steel making has already now the potential to decarbonize almost completely. However, the shift from primary to secondary steel making depends on the availability of scrap steel (EC, 2019a). Further issues on recycling scrap steel are discussed in section 2.2.2.

In 2016, almost 60% of crude steel in the EU and more than 70% worldwide was produced by primary steel making. But secondary steel making based on renewable energy, has already now the potential to decarbonize almost completely.

In 2016, almost 60% of crude steel in the EU and more than 70% worldwide was produced by primary steel making (IEA, 2017; EC, 2019a). In 2017, world steel production accounted for 1,689 million tons, almost half of it was produced in China (World Steel Association, 2018). The worldwide GHG emission intensity reached 1.83 tonnes CO_2 per tonne crude steel. The total CO_2 emissions in 2014 amounted to 2,800 million tons (Dietz & Gardinger, 2018). In the last 50 years, energy intensity in the steel industry decreased by more than 60% (World Steel Association, 2019). Energy intensities of the main production routes are listed below.

Global average energy intensity of the main production routes (IEA, 2017):

Production routes of primary steel making:

- Coke-based steel making in blast furnaces and basic oxygen furnaces (CO-BF-BOF): 5.19 MWh/ t crude steel
- Smelting reduction/ basic oxygen furnaces (SR-BOF): 5.94 MWh/ t crude steel
- Reduced iron-electric arc furnace (DRI-EAF): 6.22 MWh/t crude steel

Secondary steel making:

- Scrap based electric arc furnace (EAF): 1.86 MWh/ t crude steel

2.1.2 Aluminium

Aluminium production is divided between primary and secondary (recycled) aluminium. For primary production, the most significant production steps are bauxite mining, alumina refining from bauxite, and smelting. In addition, a carbon anode needs to be produced for the smelting process. The secondary aluminium process includes scrap pre-treatment, melting, and refining. Both primary and secondary aluminium production includes downstream processing such as rolling, intrusion and casting (EC, 2019a).

For bauxite refining, almost all plants use the Bayer-process, which requires approx. 20% of final energy demand. The smelting process is by far the most energy-intensive (approx. 80% of final energy demand) step of primary aluminium production. Almost all smelting facilities use the Hall-Héroult (H-H) smelting process, in which a high electrical current reduces alumina to liquid aluminium

The smelting process requires a carbon anode, which has to be renewed about once per month (EC, 2019a). A so-called anode effect is an operational disruption where alumina is insufficiently dissolved during the electrolysis. Anode effects lead to increased energy demand, lower operating efficiency and emissions of CO_2, carbon monoxide and perfluorocarbons PFCs[1] (EC, 2019a). In 2014, the PFC emissions were equal to around 4% of GHG emissions in the aluminium sector and had a mean PFC emission intensity of 0.61 tCO_2e/t Al (IAI, 2019).

Secondary production of aluminium is around 93% less energy-intensive than primary aluminium production. The emission intensity is 0.3 tCO_2/t of secondary aluminium, only a fraction of the emission intensity of primary production.

All other production steps only contribute with around 2% to the energy consumption of primary production processes (EC, 2019a). Annually, around 60 million tons of primary aluminium are produced globally, having an average emission intensity of about 13.5 tCO_2 per tonne of primary aluminium (Material Economics, 2018). In 2014, direct, process-related CO_2 emissions from primary production amounted to 1.53 tCO_2/t of primary aluminium (IEA, 2017). In total, primary aluminium production was demanding roughly 4% of the global industry electricity demand (about 6.2 EJ) in 2014 (IEA, 2017).

Secondary production of aluminium is around 93% less energy-intensive than primary aluminium production. The emission intensity is 0.3 tCO_2/t of secondary aluminium, only a fraction of the emission intensity of primary production (Material Economics, 2018). Annually, around 30% of the aluminium is produced from scrap. The share of secondary aluminium has been increasing steadily in the last decades (IEA, 2017). Recycling developments are further discussed in section 2.2.2.

The total emissions of both primary and secondary aluminium production in 2014 were equivalent to around 800 $MtCO_2e$, including PFC emissions which have been equivalent to 34 Mt of CO_2 in 2014 (Dietz, Jahn, & Noels, 2019).

Global average energy intensity of the main production routes (IEA, 2017):

Primary aluminium:

- Alumina refining 3.5 MWh/t (2014)
- Alumina refining under BAT conditions 2.88 MWh/t al
- Smelting 14.3 MWh/t al (global average 2014)
- Smelting under BAT conditions 13 MWh/t
- Downstream processing 0.28 MWh/t al (2014)

Secondary aluminium:

- 1.3 MWh/t al (2014)

[1] Perfluorocarbons (PFCs) are a very persistent greenhouse gas (up to 50,000 years) with high global warming potentials (7,390–12,200) compared to other greenhouse gases (EPA, 2018)

2.1.3 Copper

The production process for copper is also divided into primary and secondary processes. In 2018, around 24 million tons of copper were produced globally. The product scope of copper consists of blister, copper anodes and cathodes. Cathodes can be converted into wire rod, billets, among others. The share of primary refined production amounted to 85% (ICSG, 2019). For the primary process, two methods are available; the pyrometallurgy process (80% of facilities) and the hydro-metallurgy process (20% of facilities). In pyrometallurgy, copper ore has to be concentrated and then follows a four-step smelting process, which includes converting, fire refining, and electrolytic refining besides smelting. For this process, a lot of different technologies are available. In hydrometallurgy, lower temperatures are sufficient as a leach solution is used to concentrate copper into sulphate, which is then recovered through copper metal through electro-winning. Both pyro- and hydrometallurgy are followed by downstream processes such as melting.

Primary copper production consumes around 8 MWh/t, secondary copper around 1.5 MWh/t, making secondary production around 80% more energy efficient (IEA, 2017). As copper can be recycled without loss of quality, higher rates for collection and re-melting are seen as one of the primary routes for reducing the overall emission intensity (EC, 2019a).

Overview of direct CO_2 emission intensities of EU-27 installations, average estimates 2005-2007[2] (tCO_2/ t product, in brackets: number of facilities) (EC, 2009):

- Cathode production (primary smelting): 1.140 (8)
- Cathode production (secondary smelting): 0.310 (7)
- Wire rod production: 0.085 (10)
- Shape (billets, cakes and slabs) production: 0.1 (8)

2.2 Emission reduction potential – what are the major mitigation options in the basic materials sectors?

The Paris Agreement's objectives of stabilizing global temperature increase below 2°C requires net carbon neutrality in developed and upper-middle income countries by mid-century. Net carbon neutrality implies that some sectors – most likely agriculture - might have some residual emissions that are compensated by for example re-forestation. The emissions volumes from production of basic materials, currently about 25% of global greenhouse gas emission (Figure 1), are too big for compensation in other sectors. Global climate objectives will only be achieved if basic material production and use becomes largely carbon neutral by mid-century. As global temperature increase is a function of greenhouse gas emissions accumulated in the atmosphere, it is equally important that emissions from basic material production decline quickly from now on, along the pathway to 2050.

The emissions from production of basic materials, currently about 25% of global greenhouse gas emission, are too big for compensation in other sectors. Global climate objectives will only be achieved, if basic material production and use becomes largely carbon neutral by mid-century

While the EU Joint Research Centre (JRC) groups low-carbon options for iron and steel into BAT and innovation technologies (Pardo

[2] More recent numbers are not publicly available

et al., 2012), a much more recent report for the European Commission (EC, 2019a), describes three categories of low-carbon options for the materials sectors, namely (i) current Best Available Technologies (BAT); (ii) Carbon Capture and Storage (CCS); and (iii) novel decarbonisation technologies.

Yet, for best structuring the discussion of mitigation options we find it most useful to build on the broad consensus that in addition to BAT, four major groups of mitigation opportunities exist for basic materials to achieve the 2050 objective:

- BAT/Efficiency improvements of existing processes
- Recycling and re-use
- Material efficiency and substitution
- New clean production processes
- Green electricity/ fuel switch/ heat recovery from combined heat&power technology (CHP)

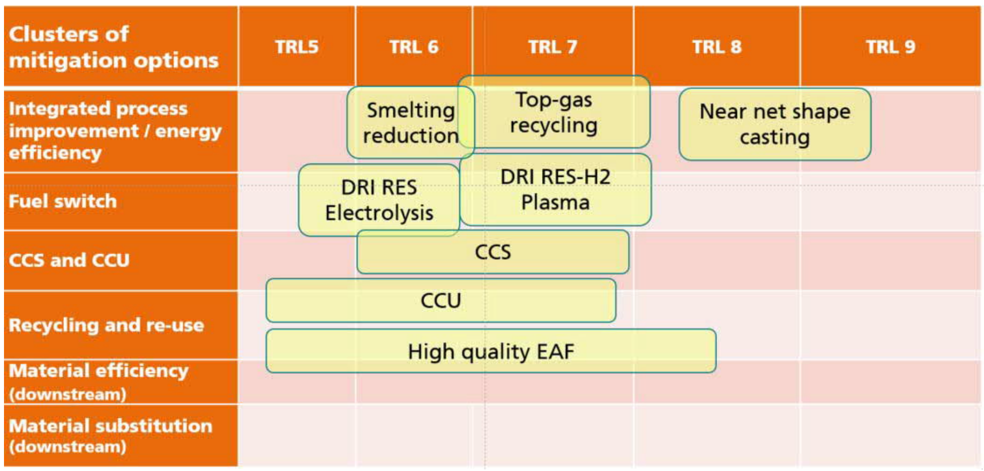


Figure 2: Technology readiness levels (TRLs) of selected mitigation options in the iron and steel sector (EC, 2019a)

Figure 2 provides an illustration of a slight variation of these categories for the iron and steel sector in relation to the technology-readiness-levels (TRLs)[3] on a scale from one to nine of the different mitigation options.

In the following, we discuss the main decarbonisation options for steel, aluminium and copper making. Next, we focus on the five main groups of mitigation options and how they can be applied to the materials.

Overview: decarbonisation options for steel

The decarbonisation of the steel sector can be achieved by three pathways: secondary steel making (recycling scrap steel), reusing or storing CO_2-intensive off-gases of the production process (CCU and CCS) or producing steel using energy from renewable sources. An increasing share of secondary steel making requires secondary steel reaching the same quality as primary steel, an adequate supply of renewable energies and an improvement in collection and sorting technologies, since

[3] TRL: Technology Readiness Level; based on a scale from 1 to 9 with being 9 the most mature technology.

steel contains different elements such as nickel from which scrap steel has to be distinguished (EC, 2019a). In the case of Carbon Capture and Usage (CCU), CO_2 intensive gases are used as input for the chemical industry. However, the process comes with some constraints: it requires additional energy and the product range is limited. Carbon Capture and Storage (CCS) is the (underground) storage of CO_2. It is not available for application yet. There are two pilot projects; the European Ulcos project, which has identified and to a certain extend developed three technologies based on CCS, and a direct reduction plant in the Middle East (EC, 2019a).

Thus, the main (potential) decarbonisation strategies are:

1. Recycling scrap steel/ secondary steel making
2. Carbon capture and use (CCU) or carbon capture and storage (CCS)
3. Producing steel using renewable energy

The best available technologies (BAT) only offer a limited potential to decrease the CO_2 intensity of the steel production process.

The best available technologies only offer a limited potential to decrease the CO_2 intensity of the production process. Figure 3 compares the carbon intensities of various steel-making technologies. The CO_2 intensity of basic oxygen steelmaking, currently the major production process with a worldwide share of more than 70%, indicated as BOF, can only slightly be reduced by optimization through the application of BATs. Using biofuels reduces emissions to a larger extend but fails to decarbonize the process and raises questions about the sustainability of biofuels. A far more efficient production can only be achieved through at least one of the three decarbonisation pathways, i.e. CCS, recycling steel in an EAF or even recycling steel and using renewable energies, which has the lowest CO_2 intensity.

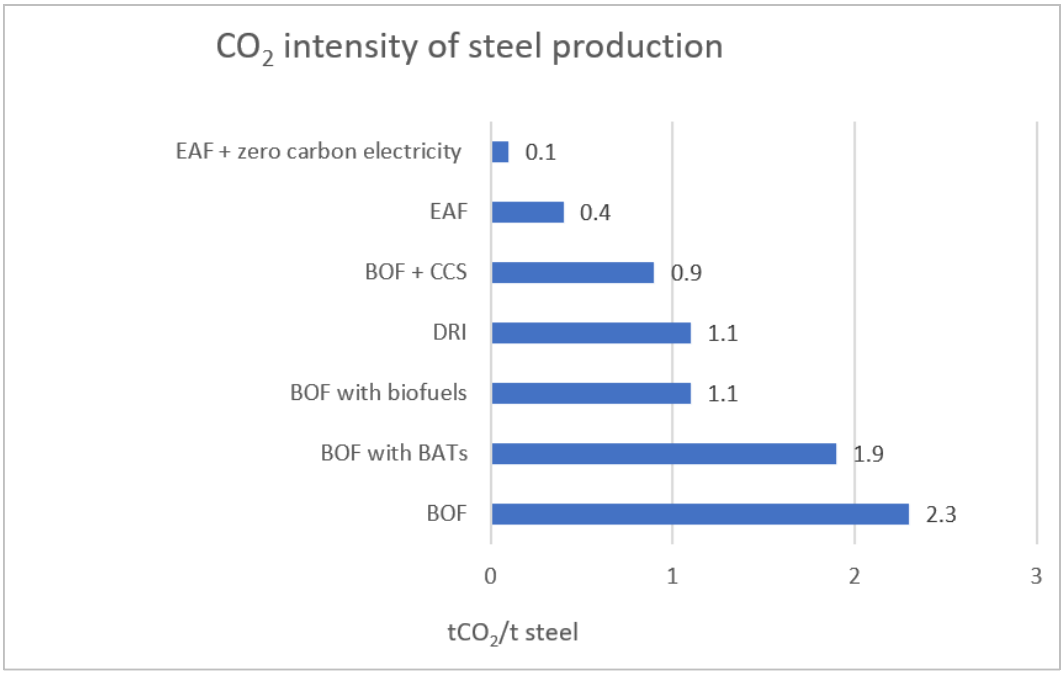


Figure 3: CO_2 intensity of different steel making technologies (in tCO_2/t steel), based on Material Economics (2018)

Overview: decarbonisation options for Aluminium

The aluminium sector has halved its GHG since 1990, mainly through process improvements and the reduction of perfluorocarbon (PFC) emissions. The European Commission presents a range of mitigation options to further reduce the emission intensity of aluminium (EC, 2019a):

1. Process improvements on current manufacturing techniques;
2. New production techniques using innovative technologies to move away from current production, more efficient and emitting less CO_2;
3. Feedstock innovations, using improved techniques to treat alumina, or sourcing aluminium from new materials with a smaller CO_2 footprint.

> For Aluminium, as the electrolysis process is by far the most energy-intensive step of the production process, improving its efficiency and decarbonizing the electricity sources are a major focus

As the electrolysis process is by far the most energy-intensive step of the production process, improving its efficiency and decarbonizing the electricity sources are a major focus. Figure 4 shows the variations of CO_2 intensity of aluminium production, indicating that especially production with coal and gas has a high emission intensity. Remarkably, the emission intensity of secondary (recycled) aluminium is only a tenth of the production with low-carbon energy sources (Material Economics, 2018).

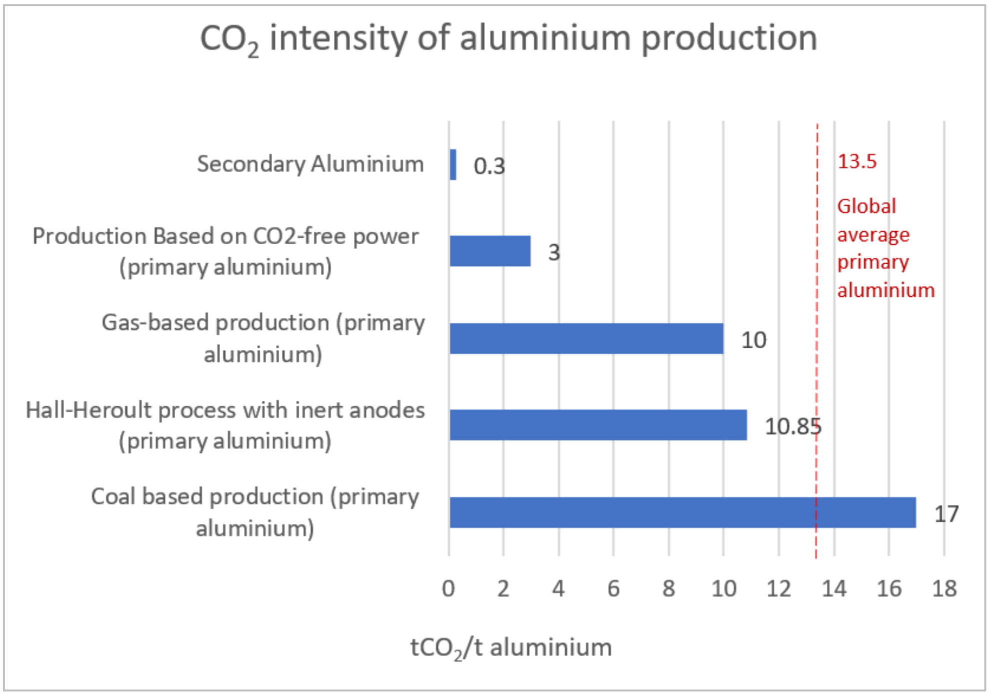


Figure 4: CO2 intensity of different aluminium production approaches (in tCO2/t aluminium), based on Material Economics (2018) and IEA (2017)

Overview: decarbonisation options for Copper

Since 1990, the EU copper sector reduced its energy consumption by as much as 60%, mainly through the installation of BATs, installing renewable energy, recycling and the reduction of process related SO_2 emissions (EC, 2019a). The EC has identified similar decarbonisation strategies to continue the mitigation in the copper sector:

1. Technology improvements
2. Use of renewable energy rather than grid-power (hydro, solar PV, wind)
3. Increased recycling

However, the reduction potential of existing production processes is seen as limited (EC, 2019a). Thus, technological breakthroughs are necessary for major efficiency improvements. Such as for the steel and aluminium industry, the energy mix plays an important role for the decarbonisation through electrification. As recycled copper products are less energy and emission intensive than primary copper, increased and improved recycling is also a promising strategy for the copper sector.

2.2.1 BAT/Efficiency improvements of existing processes

So far, the focus has been on incremental changes and efficiency improvements, which are generally identical with the so-called best available technologies. The potential of BAT is, however, limited.

Steel

Today´s BATs are mainly optimizations of conventional production processes, e.g. in the raw material preparation or the optimization of basic oxygen furnaces (BOF), the most common production route. Reaching BAT energy performance levels worldwide in all steel production routes would save 9 EJ per year of final energy consumption. As comparison, the whole global industrial sector accounted for 154 EJ final energy consumption in 2014 (IEA, 2017). Worldwide BAT energy performance levels and a higher penetration of commercial less energy-efficient production routes will not comply with the well below 2° target (IEA, 2017). The modelling by Joint Research Centre (JRC) also shows that BATs for primary steelmaking have a minor effect on CO_2 emission and energy efficiency gains (Pardo et al., 2012). The set of available technology options might achieve only 10-20% emission improvements for the European installations in the process of next refurbishments (approximately 15-year cycle of furnaces) (Neuhoff et al., 2014).

Table 1 provides a short overview of selected fields for the application of BATs and the range of emission reduction potential. For more detail on the corresponding technologies, see Table 4 in section 5.1.

Table 1: BAT emission reduction potential (EC, 2019a; BREF notes, 2013)

Production stage	Range of emission reduction potential
Primary steel making	
Raw material preparation	Up to 97.5 kg CO_2/ t coke Up to 18 kg CO_2/ t crude steel Up to 23.8 kg CO_2/ t sinter

Iron making/ optimisation of BF	Up to 119 kg CO_2/ t crude steel Up to 212 kg CO_2/ t iron Up to 20% GHG emissions Up to 18% fuel saving Up to 13% oxygen consumption
Steel making/ optimisation of BOF	Up to 23 kg CO_2/t liquid steel Up to 24 kg CO_2/ t crude steel
Alternative iron making	
COREX process (similar: FINEX process)	Up to 20% GHG emissions Up to 18% fuel savings Up to 30% NOX
Secondary steel making	
Optimisation of EAF	Up to 6 kg CO_2 / t crude steel Up to 7.5% reduction in EAF energy requirements

Aluminium

If all available BATs were implemented in the global primary aluminium production, the energy demand would only decrease by about 4% (IEA, 2017), hardly enough to achieve the necessary emission reductions. It is therefore important to consider technologies that are currently in their R&D phase, as well as increasing the share of renewable electricity for the primary aluminium production.

If all available BATs were implemented in global primary aluminium production, the energy demand would only decrease by about 4%

Moreover, if all available BATs for secondary production were implemented, the final energy consumption would decrease by around 28% (IEA, 2017). As the energy demand of secondary production is only around 5% of the energy demand for primary production, implementing all BATs for the secondary production would also not be sufficient to achieve significant energy demand and emission reductions. Table 2 shows selected BATs for the aluminium sector and their emission reduction potential or energy efficiency gains. Further details can be found in Table 5, section 5.1.

Table 2: Selected BATs for aluminium production (EC, 2019a; IEA, 2017)

Production stage	Technology	Range of reduction potential
Primary aluminium production		
Alumina Refining (Bayer process)	Natural gas as fuel	Up to 5% carbon emission savings if replacing oil as fuel
	Fluidised bed calcination	Up to 15% energy savings in Bayer process
	Tube digester	Reduces energy consumption
Smelting process (electrolysis)	Point Feeder Pre-bake cells (PFPB)	Low PFC emissions, electricity consumption decreases up to 30%

	Anode design (pre-heating, slotted or perforated)	Energy savings
	Point Feeder Pre-Baked anodes	Energy savings between 10-30%
Combined plants	CHP and waste heat co-generation	Save of up to 15% of primary fuel
Secondary aluminium production		
Pre-treatment of scrap	New de-coating equipment	30-50% energy savings
Melting process	Recuperative burners	Up to 50% energy savings

Alumina Refining

The Bayer process can be improved by upgrading rotary kilns with fluidised bed calcination, which can lead to energy savings in the Bayer process of up to 15%. This technology has a TRL of 9 and is already widely applied (EC, 2019a). The installation of innovative tube digesters can keep the energy demand of the Bayer process around 2.8 MWh/t Al (current BAT level). Although they have a high TRL of 8, tube digesters are, however, only compatible with the outline of few plants. Installing a CHP and waste-heat co-generation plant (TRL level 9) has a fuel reduction potential of 15% (EC, 2019a).

Anode related opportunities

With design upgrades of the anode used for the electrolysis, efficiency gains are possible with technologies that already have a high TRL. Electricity and emissions can be saved for the anode (electrolysis process), e.g. by installing slotted anodes. The use of Point Feeder Pre-Bake (PFPB) anodes is already widely spread (TRL of 9). With this technology, electricity savings between 10-30% are possible (EC, 2019a).

Combined plants

As production steps are in proximity, combined plants offer possibilities for improving energy efficiency. The installation of a heat recovery system, which makes heat from the electrolysis available for the Bayer process, can lead to efficiency gains between 0.8 and 1.3 MWh/t al (EC, 2019a).

Secondary production

Improved pre-treatment of scrap with new de-coating equipment can lead to fuel savings up to 50% (TRL of 9). Energy efficiency gains through recuperative or regenerative burners have a high TRL of 8-9. Enhanced furnace design can save up to 30-50% of energy (EC, 2019a).

Copper

The most prevalent BAT for smelting is called Outokumpu process (flash smelting), which has been developed 50 years ago. A newer technique is called Oxygen Flash Technique, which has a TLR of 8 and is an efficient method of smelting copper. Another BAT is waste heat recovery, with which power can be generated that can be used for the production process. In the downstream process, magnetic billet heating can increase energy efficiency. Overall system efficiency is 50-60%. Although likely applicable in the pyrometallurgy process, CCS has not yet been developed for the copper production. Application of CCS in the copper industry also depends on developments in other industries (EC, 2019a).

2.2.2 Recycling

Recycled materials require only a fraction of the energy and have a much lower emission intensity. Increasing secondary production is therefore a key decarbonization strategy.

Compared to primary production routes, recycled materials require only a fraction of the energy and have a much lower emission intensity. Increasing secondary production is therefore a key decarbonisation strategy. The recovery of material is better for steel, aluminium and copper than for most other materials due to high material value – scrap prices of several $100/t require the protection of railway wiring, for example. Yet, in some areas, like packaging, there is still significant improvement potential. The quality of recycling remains an issue, as significant pollution of recycling inputs implies that the quality of recycled materials is gradually declining and no longer suitable for high value applications.

But climate objectives cannot be achieved based on recycling alone

Important contributions to climate objectives are therefore product designs that allow for clean dismantling, practices and business models that result in enhanced scrap recovery rates, avoiding pollution of scrap (e.g. avoiding compound materials), enforcing product standards that facilitate recycling, and improved recycling technologies.

All recovered scrap is already used today, reflecting strong economic benefits, such that enterprises do not require additional incentives or rewards for shifting from primary production to recycling.

However, climate objectives cannot be achieved based on recycling alone, as:

(i) global demand for many products and services that require materials continues to increase;
(ii) materials that are included in buildings, infrastructure and long-lasting products can only be recovered at the end of the lifetime – meaning that, particularly in emerging and developing economies, additional infrastructure and products require additional new material; and
(iii) material recovery rates and quality are unlikely to reach full circularity (100%).

Wyns et. al. (2019) present policy options for enhancing the quality of recycled basic materials to preserve material value and for improving material efficiency in manufacturing and construction.

Secondary steel production

Secondary steel making is carried out in Electric Arc Furnaces (EAF), where scrap iron is melted and refined under the usage of high amounts of electric energy. The average energy intensity is far lower than the energy intensity of primary steel making (see 2.1.1, global average energy intensities). Compared to primary steel making, a CO_2 emission reduction of more than 90% and energy savings of approximately 70% can be reached (EC, 2019a). Whether scrap-based steel making can replace primary steel making and reduce emission intensity in the long term depends on whether i) secondary steel can reach the same quality, ii) a sufficient amount of scrap is available and iii) sufficient renewable energy is available.

Whether scrap-based steel making can replace primary steel making and reduce emission intensity in the long term depends on whether i) secondary steel can reach the same quality, ii) a sufficient amount of scrap is available and iii) sufficient renewable energy is available.

At the present stage, recycled steel has too many impurities to be used for high performance application. Secondary steel is mainly used for basic construction steels, while primary steel is required for more demanding product groups. Quality could be enhanced if processes to dismantle products more carefully at end of life, to sort better and to separate scrap from purer varieties were improved (Material Economics, 2018).
In today´s supply chains scrap with very different content is mixed together, resulting into the downcycling of steel. Alloy-to-alloy sorting, which is under rapid development, could avoid the downgrading as it enables knowledge on the different contents of steel for the secondary production (Material Economics, 2018). One other major challenge is the contamination of secondary steel with copper since already low levels drastically decrease the quality. Currently there are no commercially available technologies which remove copper from steel once it has been added (Materials Economics, 2018) and upcycling methods are still in the early stages of research (Wyns et al., 2019)

Wörtler et al. (2013) expect that the scrap availability will rise from 64 Mt in 2016 to 136 Mt in 2050 in the EU-28; the whole EU crude steel production is estimated to rise to 236 Mt in 2050 (Wörtler et al., 2013). Although regional application will vary, it can be expected that secondary steel can increase its global share to 50-75% by 2050 (Bataille et. al, 2018).

Secondary aluminium production

Secondary aluminium has up to 98% less emissions and is around 95% less energy-intensive than primary aluminium, making it a very attractive decarbonisation strategy (Material Economics, 2018). Here, collection rates and quality of collected aluminium play a significant role. Whereas in some parts of the world collection rates are already relatively high, improvements are necessary in others (IEA, 2017). A similar picture emerges with respect to the use of secondary aluminium in different sectors: the recycling rates for aluminium used in the construction and automotive sector are significantly higher than for consumer goods (Wyns et al., 2019).

For the expansion of secondary aluminium production, collection rates and quality of collected aluminium play a significant role, both of which need to be increased.

One approach to increase efficiency is the introduction of so-called 'Aluminium Mini Mills' in urban areas. As they are close to the areas where scrap is produced and collected as well as to areas with a high demand for aluminium products, the amount of energy intensive steps is reduced. For example, Aluminium Mini Mills avoid the shipping of scrap oversees for sorting purposes. This technology can save up to 84% of primary energy and has a TRL of 6 (EC, 2019a).

However, preventing downcycling of aluminium remains as one of the key issues. Aluminium is seldomly used in its pure form but contains a range of other elements. The quality for a specific purpose can only be ensured if the alloying composition keeps within a tight range. Most alloying elements cannot be removed after they have been added. Due to these challenges, secondary aluminium production today downcycles end-of-life aluminium into cast aluminium, limiting the range of application. Currently, a large share of recycled aluminium is used in the transport sector. In the long term, the amount of scrap will exceed the demand for cast aluminium. Preventing downcycling could enable a high-quality secondary aluminium. This requires an enhanced separation and sorting of scrap (Materials Economics, 2018). Installing innovative sorting technologies, which have a TRL of 5, can also allow for energy savings up to 12% (EC, 2019a; Cusano et al., 2017). A greater efficiency can also be achieved by increasing alloy separation through improved collection systems. Material efficiency can further be increased by designing products for recycling, so that losses in quantity and quality can be reduced (Material Economics, 2018).

Secondary copper production

The number one approach to decarbonise the copper process is the increase of secondary copper production since copper produced from recycled scrap uses merely 20% of the energy required for making primary copper (EC, 2019a) Unlike other materials, recycled copper is characterized by its high quality since it matches the quality of new copper.

Unlike other materials, recycled copper is characterized by its high quality, matching the quality of new copper.

In Europe, about half of the used copper comes from recycling and three production sites even only use scrap as raw material (EC, 2019a). Here, improved collection systems are crucial to ensure increased supply of scrap copper. The International Copper Study Group (ICSG) estimates that around 30% of the global copper use in 2016 came from recycled copper. However, secondary copper production accounted only for 17% in 2018 (ICSG, 2019). Like with other metals, key barriers of recycling are the ability to isolate the material and the infrastructure to handle it (EC, 2019a).

2.2.3 Material efficiency

Material qualities, product and building design and production and construction practices that result in more efficient material use will be key elements of a decarbonisation strategy. They can also compensate potential increases in production costs for climate friendly materials and thus avoid additional costs for consumers. All material efficiency will reduce the volume of primary material production and accelerate the shift towards a more circular economy.

Steel

If materials are used more efficiently in products and services, then climate benefits can be achieved together with material costs savings. Using more advanced high-strength steel has the potential to cut materials use up to 30-40%. Another possibility is to reduce over-specification; a large amount of steel is used in excess to what is strictly required to meet design specification (Material Economics, 2018).

Using more advanced high-strength steel has the potential to cut materials use up to 30-40%.

For example, in the automotive sector fuel efficiency standards incentivized the use of higher value (and thus lower weight) steel and contributed to a reduction of steel demand by 17.5-25% (Carruth et al., 2011). Studies for the construction sector point to weight-savings and thus carbon emissions savings potentials of 26% by improving the production material efficiency in automobile manufacturing from 56% to 70% (Horton & Allwood, 2017).

Aluminium

In the primary aluminium production, replacing bauxite as a raw material can lead to energy savings (12-46%) during the alumina refining. This technique is, however, only in its R&D phase and has a TRL of only 1-2 (EC, 2019a).
Today, the building and mobility sectors account for about half of the global aluminium demand. In future, demand in these sectors is likely to change, e.g. due to significant savings in the building sector. Factors like changed ownership structures in the car sector can also affect the aluminium demand, as the demand for materials in cars is expected to decrease by as much as 75% by 2050 (Material Economics, 2018).

Copper

Copper-based technologies can increase the energy efficiency of certain processes. For instance, thermally regenerative batteries, based on copper electrodes, can convert low-grade waste heat, currently released during many industrial, geothermal and solar-based processes, into electrical power (EC, 2019a). Energy losses can also be reduced if copper instead of aluminium is used as a conductor in an electric system, saving more than one third of the aluminium energy requirements of the same diameter. The decrease of carbon emissions depends on the energy mix of the respective country (ICSG, 2018).

2.2.4 New clean production processes

Steel

Two main approaches exist for clean steel making: (i) carbon capture and (ii) shifting from coal to direct electric or electricity-based hydrogen processes. These technologies are at level of large-scale pilots and demonstration projects. In general, the main challenges are (i) availability, public acceptance, and scale of storage sites for CCS and CCU; (ii) availability of sufficient scale of electricity from renewable sources. Viability is therefore significantly enhanced with successful

For new production processes, the main challenges are (i) the availability, public acceptance, and scale of storage sites for CCS and CCU; and (ii) the availability of sufficient scale of electricity from renewable sources.

material efficiency and recycling strategies, reducing the amount of primary steel and thus the amounts for carbon to be captured and renewable energy to be used.

CCU/CCS

CCU involves a number of constraints, for example i) it requires additional energy, ii) the amount of CO_2 exceeds the quantity of products that could be produced of it, iii) the range of possible products is limited. The technology readiness level lies between 5 and 7 and, the market entry can be expected to be 2030 or later. Arcelor Mittal currently builds a demonstration plant in Belgium, first production is expected to be in mid-2020, and ThyssenKrupp runs a project where commercialization is scheduled beyond 2030 (EC, 2019a).
CCS has the potential to make deep cuts while maintaining today´s production routes. It can be applied in different production technologies, e.g. smelting reduction with CCS (e.g. HIsarnas), top gas recycling blast furnace with CCS or near net shape casting. For instance, near net shape casting, with a TRL between 8 and 9, has an emission reduction potential up to 60%. CCS Pilot projects are under way in Europe (the Ulcos project) and in the Middle East (EC, 2019a).

> Hydrogen-based production can be close to CO_2-neutral if using renewable energy.

Hydrogen-based steel making

Hydrogen-based production can be close to CO_2-neutral if using renewable energy. CO_2 emissions can be reduced by up to 95%, with the residual emissions contained in the carbon embedded in steel. At carbon prices between EUR 34 and EUR 68 per ton CO_2 and electricity prices of 40 EUR/MWh, it eventually becomes competitive with coal-based steel making in Europe (EC, 2019a). With current carbon prices around EUR 25, there is a lack of competitiveness. Furthermore, a sufficient amount of renewable hydrogen has to be available for a cost-competitive price. Depending on the concept, the technology readiness level (TRL) lies between 5 and 7 (EC, 2019a). Three Swedish companies, in collaboration with the Swedish Energy Agency, are piloting the system.

Electrolysis of iron ore

The electrolytic process directly reduces iron ore to iron. If electricity from renewable energy is used, production can be close to CO_2-neutral. The concept is still under development (TRL 5-6), but progress seems promising. Moreover, it might be more energy-efficient than steel making by hydrogen using renewable energies (EC, 2019a).

Aluminium

Decarbonisation with CCS and CCU

As the CO_2 emissions from the electrolysis are diluted, capturing carbon is not straightforward. Especially for plants with the Hall-Héroult process, which is most plants, CCS is not commercially viable (IEA, 2017). The TRL for CCS and CCU is only 3-4 (EC, 2019a).

Alumina reduction

As an alternative to the H-H process, carbo-thermic reduction of alumina does not use electrochemical processes. Instead, alumina and carbon are reacted at very high temperatures to form aluminium. The technology could reduce energy demand by up to 30%, but only has a TRL of 2-3 and is not expected to be available before 2050 (EC, 2019a).

Anode-related improvements

Conventional anodes are carbon based and as the anode gets consumed during the smelting process, process-related emissions occur. Inert anodes are made from other materials than carbon have the potential to eliminate process-related CO_2 and PFC emissions (IEA, 2017). Inert anodes are still in their testing phase (TRL of 5) but are highly likely to find widespread application (EC, 2019a; Moya et al., 2015). Once available, inert anodes have the potential to reduce emissions of the H-H process by as much as 1.65 tCO_2/t aluminium (IEA, 2017).

Less developed approaches during the electrolysis include wettable cathodes. Wettable cathodes lower the anode-cathode distance and achieve energy consumption by up to 20% (EC, 2019a). The inert anode and wettable cathode technologies are combinable into the so-called ‘Elysis’ process. This process allows for a smelting process without direct carbon emissions and lower energy demand (up to 55%). The process is in its demonstration phase and is likely to be commercially available within the next five years (TRL of 6) (EC, 2019a).

Copper

Decarbonisation strategies with CCS have yet to be researched or developed for the copper industry. The main application could be the primary smelting process in pyrometallurgy. The application of CCS in the copper industry also depends on the development in other industries (EC, 2019a). Copper extraction using electrolyse can be defined as novel technology with a TRL between 2 and 3. It is a similar process like the aluminium H-H cell and greatly simplifies metal production. Current work on it by MIT researchers builds on earlier electrolyse techniques and increases the overall efficiency for electrolytic extraction of copper from 26% to 56%. Further efficiency improvements, e.g. through the modification of the ell design, seems possible (EC, 2019a).

2.2.5 Green electricity, fuel switch, combined heat and power (CHP)

Switching production factors to electricity massively increases overall electricity demand, which solar and wind power plants would need to generate. Thus, investments in the electricity sector need to take into account the additional demand from the materials sector and provide material producers with secure and low-cost electricity on the long run. Vast amounts of intermittent wind and solar power need to be integrated, for example by more flexible demand that adjusts the time of demand to the price of electricity.

Steel

> The decarbonisation of the steel sector largely depends on the availability of electricity from renewable energies

As explained above, decarbonisation of the steel sector largely depends on the availability of electricity from renewable energies. Secondary steelmaking in Electric Arc Furnaces (EAF), hydrogen-based steelmaking or the electrolysis of iron ore have the potential to be close to carbon neutral, if electricity comes from renewable sources (EC, 2019a). Combined heat and power from waste heat can reduce the energy requirements of secondary steel making by generating electricity. Although the process is commercial, there is only a low uptake due to the harsh working environment (chemical substances, high temperatures) in EAFs (EC, 2019a).

Conversely, green electricity does not significantly reduce CO_2 emissions from primary steelmaking due to the carbon intensive chemical processes (Material Economics, 2018).

Primary aluminium

In the alumina refining, the so-called Bayer process can be improved by upgrading to natural gas as fuel, fluidised bed calcination and installing innovative tube digesters. The efficiency gains range from 5-15% for this process and have a high technology readiness level. Installing a CHP and waste-heat co-generation plant (TRL level 9) can reduce fuel consumption by 15%.

As electricity is required for the electrolysis (smelting) process, switching to low-carbon electricity sources has a big influence on the emission intensity of aluminium (see Figure 4). There are several facilities which are already using hydro or nuclear power as an electricity source, resulting in an improved emission performance (EC, 2019a).

Although low-carbon electricity sources are commercially available (e.g. hydro, nuclear, wind and solar power) and become increasingly advanced, it will remain a challenge to fully switch to low-carbon electricity sources for primary aluminium production. In some estimates, the primary aluminium demand will grow so rapidly until 2050 that the amount of electricity that India uses today per year (1,335 TWh) would be necessary to cover the future demand of low-carbon electricity (Material Economics, 2018), indicating that switching to electricity-based processes will only prove viable when combined with other measures.

Efficiency load management in the aluminium sector has the potential to support the integration of renewables into the grid. Some facilities, like the TRIMET facility in Germany, can increase or decrease their production by 25%, allowing the company to manage the amount of electricity drawn from the grid. By lowering the energy consumption at peak demand, the facility can save costs and facilitate grid integration of intermittent renewable power sources. This 'virtual battery' concept has concluded its test phase in 2017 and is expected to be widely applied (IEA, 2017).

Copper

The copper production process requires a sufficiently large and stable power supply. A technological breakthrough in electricity storage would create new opportunities for the direct use of renewable energy sources. Nevertheless, an electrification also requires a more predictable electricity market and long-term investments (ECI, 2014). The smelting copper process can potentially split into a thermal component, using (renewable) energy, and reducing agent from biocoke. The potential route is broadly similar to the electrification of primary steelmaking. However, there are little information available. Biofuels are currently no option to replace thermal energy sources since the production process of copper requires high temperatures. This limitation will might be overcome with the development of new biofuels or jet fuel (EC, 2019a).

2.3 Key Issues

With declining overall demand for basic materials, green field investments in new production facilities with conventional technologies may be of less importance. This raises the question whether green field investments, even if pursued with existing best available technologies, should qualify for green bonds or whether this would ultimately contribute to carbon lock-in. This has

been extensively discussed in the case of investments into the most efficient coal power stations: these had been warranted support from revenue streams generated under the clean development mechanism (a project based emission reduction mechanism agreed under the Kyoto Protocol to the UN framework convention of climate change, UNFCCC) until it became obvious that, as long-term investments with lifetimes of around 40 years, they are not in line with long-term climate goals.
The focus of green bond issuance at the material production stage may therefore need to reside in investments in new production technologies that are (near) carbon neutral. Where such technologies (like in most instances) require the availability of carbon free electricity, it will be necessary to demonstrate that this supply can be served without leakage effects, i.e. without negative impacts on the carbon intensity of the remaining power demand in the country of production or, in the case of integrated (cross-border) markets, in the corresponding power market.

Recent studies have emphasized the importance of circularity elements for the industry. Relevant new technologies, practices and business models may deserve consideration for green bond issuance.

2.3.1 Emerging questions

Financing new climate friendly production processes

Many climate friendly processes are electricity-based and, combined with carbon neutral power supply, can achieve the required levels of deep decarbonisation. Should green bond issuance hence require carbon neutrality of power provision? This could encourage industry and governments to secure such supply and suitable policy framework, but if formulated too strictly may delay investments in new processes (technologies) necessary already prior to carbon neutrality of power supply.

Many existing production processes, for example for aluminium smelting or electric arc furnaces (EAF) for steel recycling are electricity based and largely carbon neutral. Would enhanced access to finance through green bonds result in a positive climate impact - and would this be necessary to justify green bond issuance? Would investors need to be demonstrated the use of additional renewable investments for electricity supply?

Financing new climate friendly materials production

Substitute materials may contribute to significant emission reductions - if investments in the production of such substitutes qualified for green bond issuance this raises the question which substitute materials should qualify? Would also established materials like wood qualify or (i) only new processes for wood-based products or (ii) wood-based construction methods; or (ii) only new materials like for example alternative cement types?

Financing improved process efficiency

Should investments in improving process efficiency or particularly efficient new installations qualify for green bonds issuance? Related questions are threefold:

First, would the benefit of short-term emission reductions outweigh the long-term impact of further lock-in with carbon intensive processes? An instructive case to consider is the controversy around the eligibility of investments in efficient coal-fired power stations under the project-based emission reduction mechanisms of the Kyoto Protocol to the UNFCCC, the so-called clean development mechanism (CDM)[4].

Second, would the entire (re-) investment qualify for green bond issuance, or only the measures linked to efficiency improvements (i.e. the incremental cost)?

Third, is it possible to identify such additional investment measures (i) in the case of new plants above best available technology; (ii) in the case of retrofit above the efficiency improvements that are inherent in periodically necessary major refurbishments?

Financing circularity elements

Recent studies have emphasized the importance of enhanced material efficiency, use of alternative materials, and recycling practices for net carbon neutrality. Can and should corresponding investments qualify for green bonds issuance? This raises questions like (i) level of improvement compared to BAU required; (ii) are new business models and experience with new practices sufficiently tangible for bond issuance?

[4] In the case of CDM, the eligibility of emission reduction projects is evaluated against the emissions baseline i.e. the emissions in the absence of the project. An efficient coal project, while performing better than the baseline at the time of construction, would eventually be outperformed by a changing energy mix and the baseline would eventually be less emission intensive than the project.

BOX 1: Mining of iron, copper and aluminum: GHG emissions and abatement options

While the primary focus of this report are the direct greenhouse gas emissions from metal production, a full life-cycle assessment of the environmental impact should also include the emissions of the main inputs to production. In particular, the production of steel, aluminum and copper relies on the mining and processing of minerals. For example, iron ore is used for steel making, while the main input to aluminum production is bauxite ore. Similarly, the manufacturing of copper requires processed copper ore in the form of concentrated copper.
The mining process of minerals generally consists of several steps: Drilling, blasting, loading and haulage, crushing and grinding. In a first step, cylindrical holes are drilled in order to prepare the blasting of the rock. This is done by using drilling machines that are powered by electricity or diesel engines. Then, explosives are used to fracture the rock. This facilitates the extraction and removal of the ore. Heavy wheel loaders and excavators load the mined material into dump trucks that are used for haulage to the processing plant. Most of these vehicles are powered by energy intensive diesel engines (Norgate et al., 2010). In the processing plant, the big fractured rocks are crushed into coarse particles. While iron ore and bauxite ore are ready for shipment after having been separated from other undesired substances in the crushed rocks, copper ore still has to be grinded and concentrated as the percentage of copper metal in copper ore is typically very low. The processing plants are usually powered by electric motors, and electricity is often generated onsite using a diesel-fuel based engine and generator (Norgate et al., 2010).

The total greenhouse gas emissions of the mining sector are non-negligible. Globally, emissions in 2016 from mining of iron ore and bauxite ore have been estimated to be 38.8 Mt CO_2e and 1.4 Mt CO_2e, respectively (Tost et al., 2018). For concentrated copper, the global greenhouse gas emissions in 2010 have been estimated to be 30 Mt CO_2e (Norgate et al., 2010). Of the considered minerals, bauxite ore has the lowest emission intensity per ton of mined product (4.9 kg CO_2e/t). While the mining of one ton of iron ore also has a relatively low emission intensity (11.9 kg CO_2e/t), one ton of concentrated copper has an emissions factor of 628.2 kg CO_2e/t (equivalent to ca. 38 kg CO_2e/t for copper ore) (Norgate et al., 2010). As can be seen in Figure A, loading and hauling account for more than 50 percent of the emissions in the mining of iron ore and bauxite ore. In contrast, the largest share of emissions in the production of concentrated copper is due to the process of crushing and grinding. However, it has to be noted that emission intensities depend crucially on site characteristics and the quality of the ore. For example, Gan and Griffin (2018) find an emission intensity of iron ore mining in China of 39 kg CO_2e/t. This is largely due to the greater average mine depth of Chinese mines and the extraction of lower grade ore. Hence, there might be substantial variation in the emissions embodied in the inputs to metal production depending on the characteristics of the mining site.

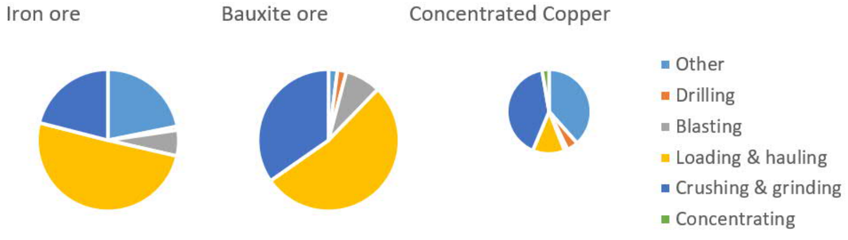


Figure A: Contribution of the different mining steps to the total emission intensity of mining. Source: Norgate et al., 2010.

Despite this uncertainty, the contribution of mining to the total environmental impact of metal production is generally regarded to be relatively small (Norgate et al., 2010; Tost et al., 2018). As can be seen in Figure B, the energy embodied in the mining and concentration process is just a small fraction of the embodied energy in the smelting and refinement stage for steel and aluminum. The mining and concentration process is more important for the total energy embodied in copper since the grinding and concentration of copper ore requires a lot of energy.

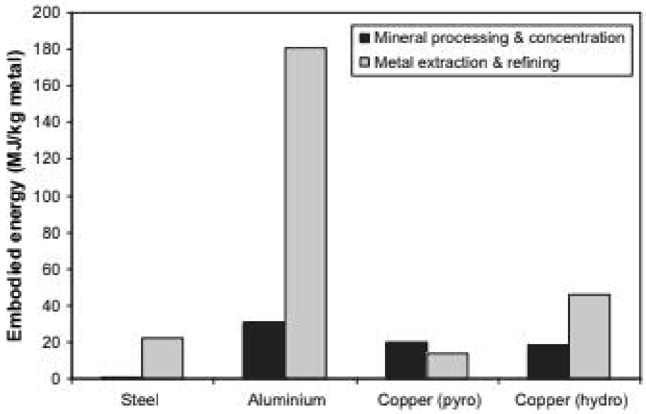


Figure B: Processing stage contributions to embodied energy of steel, aluminum and copper production (Norgate et al., 2010).

Nonetheless, abatement of greenhouse gas emissions in the mining sector is important as the sector's energy consumption and greenhouse gas emissions are projected to increase in the future. In particular, the depletion of easily accessible high-grade metal ore deposits and the shift to more complex and finer-grained metal ore deposits are expected to increase the energy intensity of the mining and concentration process (Nuss & Eckelman, 2014). Consequently, it is important to consider possible abatement options despite the relatively small current emissions intensities.

Mining companies can draw from a variety of options to mitigate their greenhouse gas emissions. In general, the emissions stem from electricity use and transportation. Hence, the main abatement options include adding renewables to the electricity supply, improving mining processes, switching to renewable fuel-substitutes, reducing waste and optimizing transportation (RMI, 2018). As Norgate et al. (2010) suggest, the iron ore and bauxite ore industry should focus on emissions from loading and hauling, while for copper ore the focus should be on grinding. In particular, emissions from loading and hauling could be reduced by improving the efficiency of the diesel engines or by switching to renewable fuel-substitutes. Research in this field is ongoing and already resulted in some market-ready innovations (e.g. a diesel-electric truck by Liebherr or a 45-ton all-electric dump truck by Komatsu) (RMI, 2018). In addition, improving mining processes through smart pit and mine design can help to reduce requirements for haulage. In the case of copper ore, Norgate et al. (2011) propose to invest in improved grinding technologies such as high-pressure grinding rolls and stirred mills. Importantly, greening the electricity supply has recently become economically viable due to decreasing cost of solar panels in some locations (RMI, 2018). This is particularly important for mines that are currently powered by onsite diesel generation. Future improvements in energy storage could make this option even more compelling.

3 The role of scenarios - a short overview of relevant climate scenarios, sectoral scenarios and roadmaps

To evaluate a company's compatibility with a climate target or a climate transition path, we need to rely on climate and economic modelling, and sector roadmaps. In general, scenarios should be plausible, distinctive, consistent, relevant and challenging (Maack, 2001).

> Under TCFD principle 2: Any scenario analyses should be based on data or other information used by the organization for investment decision making and risk management. Where appropriate, the organization should also demonstrate the effect on selected risk metrics or exposures to changes in the key underlying methodologies and assumptions, both in qualitative and quantitative terms.

The science-based target (SBT) method consists of three components: a carbon budget, an emission scenario and an allocation approach at company level. As described in the Fifth IPPC Assessment Report, the global carbon budget is set to limit the rise of global temperatures to 2°C compared to pre-industrial levels (IPCC AR5). The 2015 Paris Accord by the parties to the UNFCCC has adopted this global carbon budget and pledged to limit global warming to well below 2°C. Emission scenarios are constructed to define how GHG emissions are allocated over time. At company level, a target is considered science-based if it is designed to keep the GHG emissions of a specific company aligned with the global carbon budget (SBTi, 2019).

In the following, we briefly discuss key approaches to construct meaningful emission scenarios. More details on each of the scenarios can be found in Annex I.

3.1 Sectoral Carbon Budget Scenarios

One approach to how the global carbon budget can be respected is to break down emissions by sector over time. The so-called Sectoral Decarbonization Approach (SDA) builds on the idea that different sectors and regions are confronted with different challenges when facing low-carbon transitions. Based on a set of assumptions, the global carbon budget is broken down into sectoral budgets that define carbon emission pathways for selected time periods. This requires a form of an integrated economy-energy model or modelling framework, which allocates emission reductions to sectors over time. The models are designed to allocate emissions by optimizing against specific time horizons and by minimising abatement costs (i.e. the costs of reducing emissions). A variety of factors enter into the specific set-up or design of the model and the corresponding assumptions about issues such as public preferences, the speed of innovation and technological learning, availability of investment capital, etc. can have a strong influence on the modelling outcomes (Dietz et al., 2018). We say: the model outcomes are sensitive to inputs and assumptions.

Sector specific benchmark scenarios for emission intensities – the approach in a nutshell

The SDA requires sector specific benchmark scenarios for emission intensities. Emission intensities are calculated by dividing emissions (e.g. tonnes of CO_2-eq.) by a measure of activity or production (e.g. tonnes of steel). As this approach basically "normalizes" the emission intensity, the approach allows for comparisons of carbon performances of single companies with the sectoral benchmark pathways.

$$\text{Emission intensity benchmark} = \frac{emissions\ [t\ GHG]}{economic\ activtiy\ [t\ output]}$$

Moreover, the approach allows for comparisons of companies' emission intensity pathways among each other, even if the companies are of different sizes (Dietz et al., 2018). This is in line with the TCFD Principle 5: Disclosure should be comparable among organizations within a sector, industry or portfolio.

The underlying scenarios – IEA's Energy Technology Perspectives

The nominator – deriving GHG emissions

The International Energy Agency (IEA) supplies sectoral emission scenarios via its biennial Energy Technology Perspectives Report (ETP). The IEA scenarios have the advantage that they are more transparent than others in that modelling inputs and outputs are accessible and moreover provided "in a form suitable for applying the SDA" (Dietz et al., 2019). The scenario model used in the 2017 ETP covers around 30 countries and regions in a time period until 2060. The IEA model considers three distinct carbon budget scenarios, which limit global warming to different global temperatures. The first scenario estimates sectoral carbon budgets and benchmark emission pathways for a reference scenario (RTS), including the NDC pledges of the Paris Agreement and resulting into a temperature increase of 2.7 °C until 2100. The 2°C Scenario (2DS) and the Beyond 2°C Scenario (B2DS), a "technology push" scenario, are consistent with a 50% chance of limiting the average temperature increase to 2°C or rather 1.75 °C by 2100 (IEA, 2017).

The denominator - deriving economic activity

In the IEA's ETP model, assumptions are made in order to estimate the global and sectoral economic development until 2060. The estimated global economic growth and historic production shares of the sectors are used to determine the sectoral emission intensities to stay within the global carbon budget.

For all scenarios, the IEA makes the same assumptions on future economic activity and population development (based on World Economic Outlook Database of the IMF for real GDP growth projections & the "World Population Prospects" of UNDESA for population projections). Changes in global energy demand are reflected in energy prices (gas, oil, coal, differentiated by region), depending on the scenario. The applied technologies and policies reaching the 2DS and B2DS scenario have an impact on demand development, e.g. oil demand and therefore oil prices are lower in the 2DS and B2DS than in the RTS scenario. A detailed discussion of assumptions and can be found in the ETP 2017 (IEA, 2017).

So what are the pros and cons of the ETP sector scenarios?

Availability of scenarios for metals sectors – steel and aluminium yes, copper no

The ETP industry sector scenarios are available for five sectors, among which are the steel and aluminium sector. This and the specific industry model (TIMES-based linear optimization model) are further described in Energy and Technology Perspectives 2017 (pp. 399-400). A further description of assumed sectoral figures and assumptions can be found on pp. 186-191 (steel) and pp. 197-201 (aluminium) of the ETP 2017 (IEA, 2017).

PRO
Easy to apply, transparent, widely used and good for comparing corporates

The carbon budget scenarios are relatively easy to apply, have a high degree of transparency and are widely used (TCFD, 2016). Another key advantage is that they facilitate a comparison between different companies in the same sector. The IEA scenarios are updated regularly, but not all sectors are covered (e.g. copper).

As with all energy-modelling frameworks, they are based on a set of assumptions and simplifications and the interpretation of results or modelling outputs needs to be done with these limitations in mind. For example, the model used by the IEA only includes commercially available technologies, which excludes the possibly disrupting effects of future technological breakthroughs (IEA, 2017). The IEA CO_2 budget is furthermore very sensitive to changes in the probability achieving a certain temperature target. For the 2DS, moving from a 50% chance to a 66% chance reduces the CO_2 budget by 25% (IEA, 2017). Moreover, results are sensitive to “on how quickly capital is turned over, on relative costs of the various technology options and fuels, and on incentives for the use of BATs for new capacity” (IEA, 2017). It is particularly difficult to incorporate factors like social acceptance, political feasibility and availability of capital in a model that optimizes on cost-effectiveness (IEA, 2017).

CONTRA
Benchmarks for evaluating corporate performance are very sensitive to assumptions and in particular choices about the allocation of the available emissions (budget) to each sector

3.2 Transition Risk Scenarios – or rather: transition compliance scenarios

(Sectoral) carbon budget scenarios can be expanded for financial risk analysis. In those (sectoral) transition scenarios the above-mentioned carbon budget scenarios are combined with risk-related parameters.

What is more relevant for the evaluation of a prospective climate bond issuer is however not the quantification of the transition risk itself, but a firm’s ability and intention (as laid down for example in the firm’s low-carbon and capital expenditure/ investment strategy) to comply with the evolving regulatory requirements and the corresponding global, national and /or sectoral emission pathways.
Basically, assessing the transition risk is about translating climate roadmaps into scenarios used for modelling the impacts on financial assets. Most models used for valuation of carbon risks build on existing frameworks, which are then expanded to include transition risk factors.

We are not interested in transition risks here but in a firm’s ability to keep its emissions transition-compliant. How can we learn from the “translation” of scenarios into firm specific risk metrics for the translation of scenarios into firm specific carbon performance metrics?

What can we learn from existing and emerging approaches to measuring transition risk for the question of how to evaluate a firm’s compliance?

For our purpose of evaluating the GHG performance of a firm, these approaches, while providing some scope for learning, are not directly relevant. But it could be interesting to explore in how far the “translation” of scenarios into firm specific risk metrics could be insightful for the translation of scenarios into firm specific carbon performance metrics.

3.3 Integrating technology options into scenarios

Roadmaps for low-carbon transitions can also be sketched by other (sectoral) modelling approaches. The models differ in scope, base year, assumptions for technological developments etc. Moreover, the modelling can pursue different aims like showing sectoral mitigation potential or effects of (innovative) technologies. The key assumptions depend on the specific approach, usually containing carbon and electricity price, (available) technologies and future production levels.

There are several scenarios and roadmaps for the steel and aluminium sector which mainly focus on technology and price developments. The Joint Research Centre (JRC) examines scenarios for the aluminium and steel sector in the European Union (Moya et al., 2015; Pardo et al., 2015).

> Due to the different modelling approaches, the scenarios used in different studies are difficult to compare and there may be difficulties when translating the findings to the firm level. The major advantage of the scenarios' technology mix and costs approach is, however, that it gives very detailed insights into the potential of individual technologies.

For the steel sector, JRC (2012) extends a model developed by Tata steel and TNO and analyses the effect of new technologies on energy consumption and CO_2 emissions in the steel sector in different scenarios based on fuel, resource and CO_2 prices. The "EU energy trends to 2030" (European Commission, 2009) provides the assumptions on future demand and production, scrap availability, energy and CO_2 prices, the exogenous variables. Besides the baseline scenario, there are two alternative scenarios which examine the influence of a variation in fuel, resource and CO_2 prices on the energy efficiency performance of the industry.

The BCG 2013 Steel´s contribution to a low-carbon Europe works on the mitigation potential in the steel sector under consideration of available technologies for the time horizon between 1990 and 2050. The model approach is based on the total carbon footprint of the EU27 steel industry, and therefore on firms´ disclosure, considering direct and indirect emissions. Four technology and two economic scenarios are developed. However, none of the scenarios provides specific information on the electricity need of the steel sector. Besides the emission reduction potential, the study analyses the effect of efficient application of steel in three other sectors (energy, traffic, household).

In the aluminium sector, the JRC constructs energy consumption and GHG emission scenarios for the EU and Iceland until 2050 based on technological developments cost effectiveness. The input data (e.g. energy consumption and costs per production process, GHG emissions, installed technologies, material in- and output) is mostly supplied by individual production facilities. The model is thus dependent on the disclosure of companies and the quality of supplied data. As data reported by companies is limited, the model relies on assumptions and estimates (e.g. technology costs, on-site electricity generation costs). Other input data, such as electricity price developments and future aluminium demand are derived from a variety of sources. The study uses the simplification that national electricity costs equal production costs, as on-site electricity costs are rarely disclosed. As the model optimizes for cost-effectiveness, electricity prices largely determine where production is allocated. The regional focus on the scenarios does not allow for incorporation of developments on the world market (Moya et al., 2015).

There are hardly any CO_2-scenarios for the copper industry. Kulczycka (2017) runs a scenario analysis to quantify the emissions from copper production from 2010 to 2050, accounting for changes in processing technologies, market shares and global electricity mixes.

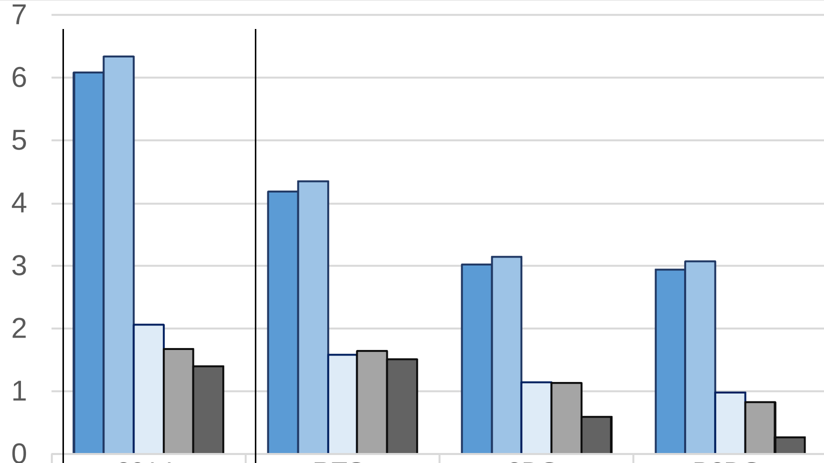
3.4 Key issues

The scenarios determine the mitigation efforts required by the sectors and ultimately, by the corresponding firms. Yet, due to the different modelling approaches, the scenarios used in different studies are difficult to compare and there may be difficulties when translating the findings to the firm level. The major advantage of the scenarios' technology mix and costs approach is, however, that it gives very detailed insights into the potential of individual technologies. At the same time, the level of detail requires a number of estimates and assumptions, which makes it very difficult to compare results across scenarios and for different technology mixes. The technology mix and cost scenario approach is furthermore highly sensitive to assumptions about the speed and extent of future technological innovations. A strength of this scenario approach is that it indicates which technologies are pivotal for the decarbonisation of the sectors. In the case of aluminium, for example, the JCR study reveals which currently underdeveloped technologies should be prioritized (Moya et al., 2015).

For the steel sector, the Transition Pathway Initiative (TPI) considers emissions of scope 1[5] and 2 for the estimation of emission intensity pathways. Since the IEA scenario only offers data on direct emissions, scope 2 emissions are calculated by multiplying the power consumption by the emission intensity of the electricity grid. For aluminium, TPI also includes emissions of scope 1 and 2, using the same calculation method for indirect emissions. Due to possible overestimations of emission intensities for companies selling alumina in the end of the production process, primary aluminium equivalents are used as reference value. Aluminium production emits one other greenhouse gas (PFC), which is not included in the IEA pathway. Therefore, TPI adjusts the benchmark pathways integrating PFC (Dietz, Jahn & Noels, 2019).

Figure 5 shows the range of emission intensities derived from TPI and IEA scenarios for steel and aluminium for 2030 and 2050. Figure 6 shows JRC's scenarios for emission intensities for aluminium in 2050.

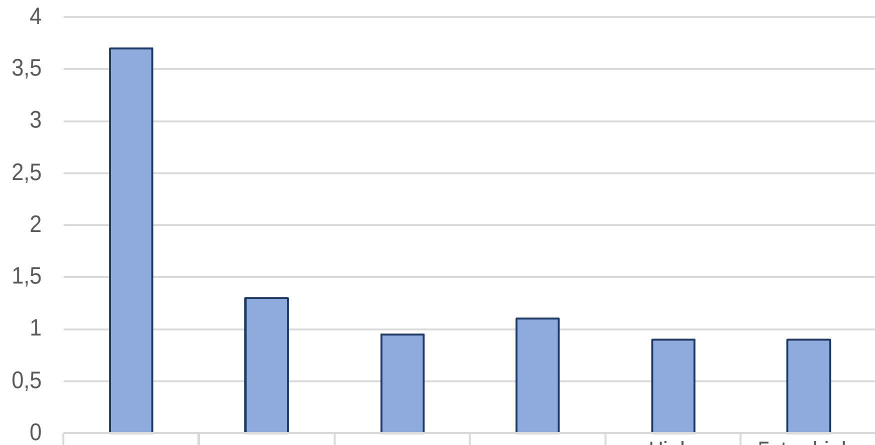
[5] Three scopes of greenhouse gases are defined: scope 1: direct emissions (from sources that are owned or controlled by the company), scope 2: indirect emissions from the generation of purchased energy, scope 3: all other indirect emissions (including upstream and downstream emissions)



	2014	RTS	2DS	B2DS
tCO2/t al (TPI 2030 scenario)*	6,08	4,18	3,02	2,94
tCO2e/t al (TPI 2030 scenario)	6,34	4,35	3,14	3,07
tCO2/t al (IEA 2050 scenario)**	2,06	1,58	1,14	0,98
tCO2/t steel (TPI 2030 scenario)	1,67	1,64	1,13	0,82
tCO2/t steel (IEA 2050 scenario)**	1,40	1,51	0,60	0,27

*excl. PFC emissions
** only scope 1 emissions (direct CO_2 emissions)

Figure 5: Overview of emission intensities across TPI and IEA scenarios, based on Dietz, Jahn, & Noels, 2019 and IEA, 2017



	2014	Low CO2 price	High CO2 price	Alternative secondary	High electricity price	Extra high electricity price
tCO2/t al (JRC 2050 scenario)	3,7	1,3	0,95	1,1	0,9	0,9

Figure 6: Overview of emission intensity of direct GHG emissions (scope 1) for primary aluminium production in the EU and Iceland, based on Moya et al., 2015

4 Translating scenarios and sector pathways into benchmarks, eligibility criteria and firm-level metrics

Based on the above discussion of scenarios and emission pathways, this section discusses how metrics, benchmarks and technical eligibility criteria can be derived to evaluate firms and assets in the materials sector. This process is the basis to demonstrate how climate change benefits of specific investments in assets and projects could inform credible impact reporting reflecting corporate low-carbon transitions.

Emission allocation at company level – convergence and contraction

To allocate emissions on company level, science-based targets are built on two different methods: convergence and contraction. Subject to the approach and the nature of the reduction target, emission pathways for the different companies can be identified.

The convergence approach can only be applied if the emission scenario is based on a sectoral carbon budget. It is assumed that the carbon intensities of the companies of a certain sector converge towards the sectoral target carbon intensity without exceeding the sectoral carbon budget. The rate of convergence of an individual company is determined by the initial carbon intensity of that company, the carbon intensity that is consistent with the sectoral carbon budget and the growth of the company relative to the growth of the sector. For instance, a company with a higher growth rate than the sectoral average growth rate must reduce the emission intensity more rapidly than a company with a lower growth rate (SBTi, 2019).

The contraction approach can be applied to an absolute or an intensity target. The latter assumes parallel emission pathways for different companies, in compliance with the sectoral carbon budget. The individual rates depend on the carbon budget and the expected level of activity of the sector. The approach of contraction of absolute emissions assumes that all companies reduce their emissions at the same rate (SBTi, 2019).

4.1 Science Based Target Approaches

The allocation methods on company level can be applied in three different approaches of Science-Based Targets: the Sectoral Decarbonization Approach (SDA), the Absolute-Based Approach and the Economic-Based Approach.

4.1.1 Sectoral Decarbonization Approach

The Sectoral Decarbonisation Approach (SDA) was developed by CDP, WRI and WWF with the technical support of Navigant (formerly Ecofys) as a consultancy partner and is based on the IEA scenarios (see 3.1). For homogenous sectors, a company's emission intensity pathway (depending on current emissions and emission targets) is compared to sectoral emission intensity pathways. It captures emissions of scope 1 and 2 and relies on companies´ reporting of their emission and production activities (SBTi, 2019).

> For homogenous sectors, it makes sense to simply compare a company's emission intensity pathway to the corresponding sectoral emission intensity pathway.

Among others, the Science Based Target Initiative (SBT) applies the SDA, using the IEA scenarios. They offer a free and publicly available excel tool that helps companies set an emission target for a self-selected commitment period. The annual activity growth rate, one of the input factors, can be calculated by the firms in different ways, e.g. by using historical data.

The Carbon Disclosure Project (CDP) uses the IEA scenarios and rates global steel companies on emission-related metrics with emission pathways as one of the key areas (Fryer, et al., 2016). Unlike TPI, which evaluates both carbon performance and targets, they only examine historic emission pathways and compare them to the emission intensity pathways of the sector. Using emission targets (it is assumed that companies meet their targets), TPI also calculates future emission pathways of single companies and compares them to the sectoral benchmark. Since there is no sectoral carbon budget scenario for copper, they apply it to the iron and steel and aluminium industry (Dietz & Gardiner, 2018; Dietz, Jahn & Noels, 2019).

4.1.2 Absolute-Based Approach

For the Absolute-Based Approach, any suitable scenario that includes an emission reduction rate, either on the global or on the sectoral level, can be used. In the approach, all companies are assumed to reduce their emissions at the same rate as required for a given scenario, i.e. the contraction of absolute emissions is used to allocate the emission reduction on the company level. Although the approach is simple, there has not been an application for the steel, aluminium or copper sector yet (SBTi, 2019). A major disadvantage is that it is difficult to apply the approach to growing companies. As the steel and the aluminium sector are both growing, it is more suitable to choose an intensity-based approach than an absolute-based approach.

> In the "absolute-based approach", all companies are assumed to reduce their emissions at the same rate as required for a given scenario.

4.1.3 Economic-Based Approach

Economic-based approaches have been developed to point out the relative emission reduction in relation to individual economic activity. The Greenhouse Gas per Value Added (GEVA) approach, for example, follows the contraction of emission intensity per value added and is intended for scope 1 emissions (Randers, 2012). The economic-based approach has rather been applied and developed for individual companies than for whole sectors. The approach is only science-based if it leads to an absolute or intensity emission reduction in line with a given scenario and there is a risk of exceeding the carbon budget. Therefore, the Science Based Target Initiative recommends to rather use one of the two other Science-Based Target approaches.

> "Economic-based approaches" focus on the firm's relative emission reduction in relation to individual economic activity.

4.2 Companies´ Target Setting

4.2.1 Absolute or intensity target

For applying the "SDA" (the sectoral decarbonisation approach), it is most suitable to set an intensity target.

The company´s target, which is compared to a benchmark by means of the contraction or convergence method and different science-based target methods, can either be an absolute or an intensity target. An absolute target is more environmentally robust and more credible for stakeholders than an intensity target, making a firm´s emission reductions predictable and transparent. Due to possible gains in efficiency, intensity targets do not exclude an increase in total emissions as absolute targets do. On the other hand, a decrease in emissions and thus the achievement of an absolute target can also result from a decline in production instead of efficiency improvements. Furthermore, achieving an absolute target may be difficult if the company grows and it does not allow a comparison between different firms (SBTi, 2019). The type of target is of importance if it comes to the application of one of the science-based target approaches. For instance, if the SDA should be applied, setting an intensity target is the most suitable.

4.2.2 Target Boundaries

For applying "Target Boundaries", the base and the target year must be chosen precisely. Credible emission data of the base year must exist, and a suitable base year should be classified.

For defining a target, boundaries, like the emission scopes, the greenhouse gases and the geographical operations, must be set. The Science Based Target Initiative suggests the inclusion of emissions of scope 1 and 2, thus emissions from company´s direct operations, and a target for scope 3 emissions if these indirect emissions cover over 40% of the total emissions (SBTi, 2019). Companies can either choose a single target for all emission scopes, or rather for emission scope 1 and 2, or choose individual emission targets. One single target ensures the inclusion of emissions along the entire value chain and provides flexibility for the company but lacks transparency. It is easier to track performances of different activities if each emission scope is captured by an individual target. Data tracking is facilitated if separate targets for different scopes have the same target period (SBTi, 2019).

The base and the target year must be chosen precisely. Credible emission data of the base year must exist, and a suitable base year should be classified. The Science Based Target Initiative suggest a time horizon of 5 to 15 years (SBTi, 2019)

4.2.3 Target reliability

To classify a bond as 'green', carbon management quality and target reliability must be ensured.

In the Science-Based Target approach, assets are evaluated based on expected pathways. To derive a future emission pathway of a company, emission and production targets must be considered. To classify a bond as 'green', carbon management quality and target reliability must be ensured.

The Transition Pathway Initiate (TPI) evaluates the carbon management quality of different firms and classifies them into five levels on the basis of 16 to 17 indicators: "unawareness", "awareness", "building capacity", "integrating into operational decision making" and "strategic assessment". It covers the companies´ management/ governance of greenhouse gas emissions and the risks and opportunities relating to the low-carbon transition. Similarly, The Carbon Disclosure Project (CDP) includes in its steel company ranking the company´s performance against their own targets.

Table 3 provides an overview of the disclosures required from companies in order to derive meaningful emission intensity trajectories. The table furthermore lists the required input data to calculate the emission intensity benchmarks.

Table 3: Overview of disclosure requirements

Theme	Data					Reference framework
	Benchmark Input Data	Unit of Measure	Required Disclosure from Company	Unit of Measure	Comment	
GHG emissions	Scope 1	Metric tons CO2e	Scope 1*	Metric tons CO2e	per production step if possible	SBTi, TCDF, CDP, GRI 305-1
	Scope 2	Metric tons CO2e	Scope 2*	Metric tons CO2e	per production step if possible	SBTi , TCDF, CDP GRI 305-2
	Scope 3	Metric tons CO2e	Scope 3	Metric tons CO2e	only necessary if scope 3 emissions cover over 40% of the total emissions	SBTi, GRI 305-3
*if data has to be estimated: method for estimation and reason for lack of data to be disclosed						
Energy consumption	Total Energy consumption	MWh	Total Energy consumption	MWh	per production step if possible	GRI, TCDF
	Electricity consumption	MWh	Electricity consumption	MWh	per production step if possible	GRI 302-1/2
Future energy consumption			Future energy consumption	MWh	per production step if possible	SBT
Emission factor of purchased electricity	National electricity mix and emission factors	Metric tons Co2e /MWh	emissions factor for the purchased amount of power from specific generation facility	Metric tons Co2e /MWh		TPI, SBT
Activity / production	Sectoral physical production levels	tons per year	Physical production	tons per year		SBT
Emission intensity			Emission intensity	CO_2e/MWh		GRI 305-4
Future emission Intensity	Future production levels (based on models)	tons per year				TPI, SBT
	Future GHG emissions (based on targets set by companies, scenario models, business strategies)	Metric tons CO_2e				TPI, SBT
GHG emission target			Base year	Year		SBT
			Target year	Year		SBT
			Absolute Target	Metric tons CO_2e or % reduction (base year)		SBT
			Intensity (scope 1 + 2 combined or separately)	Metric tons CO_2e per activity or % reduction of intensity measure		SBT

Energy efficiency & energy reductions			Energy efficiency (total energy consumption divided by production output)	MWh/t		GRI 302-3
			Energy reductions achieved as result of conservation efforts	MWh/t	per fuel type if possible	GRI 302-4
Emission reductions			Emissions reductions achieved as result of initiatives	CO_2e/t	per emission type is possible	GRI 305-5
Technology Mix	Data on Best-in class technology developments		BATs installed			TCFD

5 Ideas for basic typologies for climate bonds relating to basic materials production

Climate bonds can build on specific technologies, taking into account how they align with long-term decarbonisation pathways. Alternatively, they could rely on company-level assessments.

5.1 Technology-based: technology portfolios from roadmaps, technology requirements from 1.5/2C pathways

Overview

A project based green bond could be based on an assessment of the specific technology. GHG reduction options for basic material production can be classified in three groups:

1. Min-10 – Minimum of 10% GHG reduction: Improvements that can achieved through available technology – typically (for example for the purpose of allocating free allowances to energy intensive installations under the EU Emissions Trading Scheme) defined by the 10% most efficient/least GHG intensive installations
2. Min-30 – Minimum of 30% GHG reduction: Measures that achieve significant improvements above the current BAT benchmark
3. NCN – Net carbon neutral: Deep decarbonisation of the production process

Ultimately, and in order to achieve net carbon neutrality, in line with global climate targets and aligned emission pathways, by 2050, only processes of the third category are suitable. If improvements of a process step deliver large-scale emission reductions at the level of that process step only, while the final material still remains relatively carbon intensive due to emissions in further process steps, it may be necessary to asses overall performance across all process steps (and emission scopes) when evaluating the eligibility of a corporate/project for green bond use of proceeds status.

Alternative specifications that would allow improvements at lower levels of emission reduction to qualify for green bonds entail two potentially significant risks:

- Lock-in of technology development with technologies that are not suitable to deliver emission reductions to the degree required for preventing catastrophic climatic change.
- Stranded asset risks for investors (as discussed for the case of critical-coal projects under the Clean Development Mechanism), if the market penetration of net carbon neutral technologies shifts the emission baseline below the emission level of installations optimised at BAT-level.

Therefore, the paper suggests for an initial concept of green/climate bonds in the materials sectors to focus eligibility on technologies of the third category above.

Data requirements and illustration

In order to assess what kind of technology portfolios offer meaningful emission reductions and energy efficiency gains, the required data has to be collected and generated in a transparent and ideally harmonised manner. An overview of the most relevant data sources and literature used for this initial assessment in this issues paper is included in the Annex.

Section 2.2 has introduced technologies in different development stages for the steel, aluminium and copper sector. Table 4 and 5 summarize key technology options and the significance of emission prevention potential for the steel and aluminium sector. Besides specifying emission reduction potential per unit of output, the table further outlines energy efficiency potentials of selected technologies. Both emission reduction potential and energy efficiency gains are divided into the three categories discussed above, according to their potential for reducing emissions compared to the 2014 reference value.

Table 4 – Overview of the emission reduction potential of selected technology options: the example of steel.

(Note: For the sake of providing for a quick overview, technology options are categorised by emission reduction potential into one of the three right-hand columns)

		Reference level 2017	Production step	Measure	TRL	Min. 10% reduction	Min. 30% reduction	Net carbon neutral ca. 90%
Primary steel making	Emission intensity	Global average CO_2 intensity: 1.83 tCO_2 / t steel	Raw material preparation	Emissions optimized sintering	BAT		appr. 30%	
			Iron making process	Smelting reduction	5-6		Up to 35% *	
				Top gas recycling BF	7	25%**		
				Coke oven gas reforming	5		30%**	
			Steel making process	COREX process	BAT	appr. 20%		
				Stove waste gas heat recovery	BAT	appr. 10%		
				Strip Casting	BAT		80-90%***	
				Near net shape casting with CCS	8-9		60%***	
				Hydrogen-based direct reduction	7			95%

				Aqueous alkaline electrolysis	4			Carbon neutral
				molten oxide electrolysis	4			Carbon neutral
Secondary Steelmaking			EAF	EAF with zero carbon electricity	BAT			95%
Primary steelmaking	Energy intensity	Global average energy intensity: 20 GJ / t crude steel	Raw material preparation	Coke-dry-quenching	BAT		Up to 40%	
			Steel making process	Variable Frequency Drives on Ventilation Fans	BAT	20%		
Secondary Steelmaking			EAF	CHP from waste heat	BAT	7.5% (to conventional EAF)		

*compared to BF-BOF steel making **compared to BF ***compared to conventional casting

Table 5: Overview of the emission reduction potential of selected technology options: the example of Aluminium

(Note: For the sake of providing for a quick overview, technology options are categorised by emission reduction potential into one of the three right-hand columns)

		Reference level 2014	Production step	Measure	TRL	min. 10%	min. 30%	Net carbon neutral ca. 90%
Primary Aluminium	Emission intensity	Global average CO_2 intensity: 13.5 tCO_2/t al	Smelting	Inert anode	5	14% (11.6 tCO_2/t)		
			Gas-based production	Fuel switch	BAT	16% (11.34 tCO_2/t)		
			Production-based on CO2-free power	Fuel switch	BAT			88% (3 tCO_2/t)

Secondary Aluminium		Global average CO_2 intensity: 0.3 t CO_2/t al						
Primary Aluminium	Energy intensity	Global average energy intensity (approx.) 18 MWh/t al	Alumina refining	Carbo-thermic Reduction	2-3		20-30% (14.4-12.6 MWh/t)	
			Smelting	PFPB	BAT		10-30% (16.2-12.6 MWh/t)	
			Smelting	'Elysis' process	6		Up to 55% (8.1 MWh/t)	
			Smelting	Kaolin Reduction	1-2		12-46% (15.84-9.7 MWh/t)	
			Smelting	Ionic Liquids	1-2		30-85% (12.6-2.7 MWh/t)	
			Combined plant (Alumina Refining & Smelting)	Cogenerati on	BAT	15% (15.3 MWh/t)		
Secondary Aluminium		Global average: 4 MWh/t al	Aluminium Mini-Mills	Lean production	6			86% (0.56 MWh/t)
			Preparation	Economic sorting	5	12% (3.52 MWh/t)		
			Melting	Recuperati ve or regenerati ve burners	BAT		30-40% (2.8-2.6 MWh/t)	

5.2 Corporate level: Science-based target appraisal, corporate strategy: Sectoral Decarbonisation Approach (SDA)

Apart from technology portfolios as described in the previous section, a firm should follow a number of criteria regarding its corporate strategy in order to qualify for a green bond:

i) Scenario compatibility
ii) Management quality
iii) Reporting requirements

The categories are largely based on TCFD's four fundamental elements that are to be disclosed by individual companies. The four thematic core elements are governance, strategy, risk management and metrics and targets, which are discussed in detail in Appendix II. The four elements are aligned with several other reporting frameworks, such as the G20/OECD Principles of Corporate Governance, the CDP Climate Change Questionnaire, the GRI principles, CDSB frameworks and the International Integrated Reporting Framework. A detailed overview of alignments with other organizations can be found in the Annex.

Broader SDG compliance /ESG sensitivities, while important for the overall integrity of a green or climate bond, are outside the scope of this report which focuses on climate change.

i) Scenario compatibility

As discussed in section 4.1.1, the Sectoral Decarbonisation Approach (SDA) is frequently used and lends itself for an application to the comparably homogenous aluminium, copper and steel sectors. The other science-based target approaches discussed above, absolute-based and economic-based, appear less applicable for deriving sectoral benchmarks.

How does it work? A company's emission intensity pathway, depending on current emissions and emission targets, is compared to its sector´s emission intensity pathway (see for example TPI, in section 4.1.1).

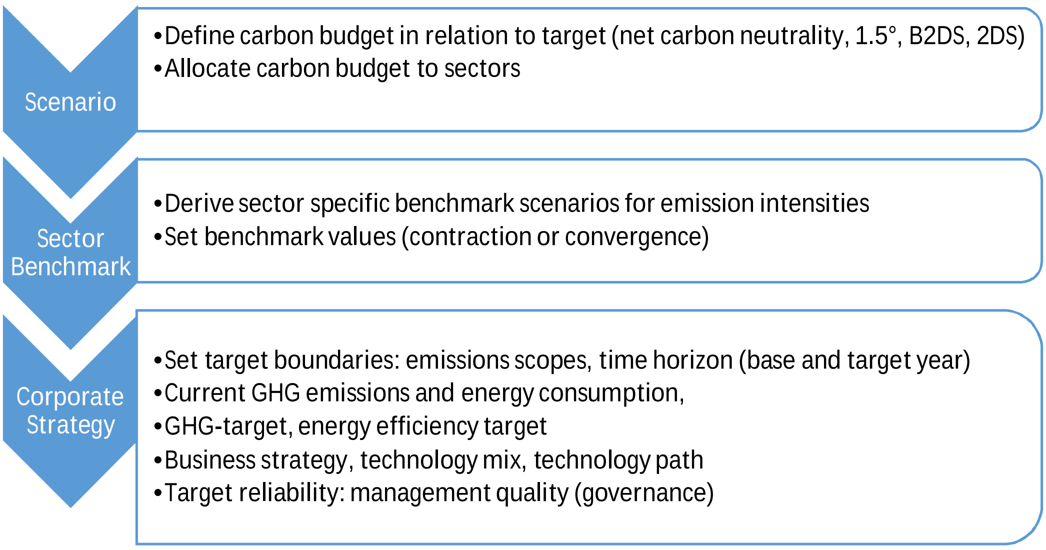


Figure 7: Illustration of the SDA-Approach

For assessing a company's scenario compatibility, its emission intensity pathway, depending on current emissions and emission targets, is compared to its sector´s emission intensity pathway (see for example TPI). A company should be familiar with the sector specific benchmarks and set out a vision as to how it is planning to reduce the emission intensity of their production output in the long-run as part of their business strategy and financial planning. Targets should be ambitious, realistic and measurable. As each company has a unique set-up and market position, an appropriate technology roadmap needs to indicate how the firm is planning to reach its targets. It is crucial that the technology roadmap includes a firm's financial plans regarding technology investments. As discussed above, implementing current (so called) best available technologies (BAT) is not sufficient to decarbonize the materials sectors. Accordingly, a firm should also set plans regarding investments in R&D and net-carbon neutral technologies and show how its mitigation efforts go significantly above BAT and efficiency improvements related to regular, cyclical technology updates.

A critical discussion of reference benchmarks and how to link them with specific decarbonisation plans and measures of a company

Technology portfolios can be assessed with intensity benchmarks. For intensity-based benchmarks, the weighted emission intensity (as a function of emission intensities of individual technologies and emission share) can be compared to sectoral emission intensity. For example, the literature expresses efficiency gains in percentage per production step, costs savings and reductions of energy per unit of activity. Depending on the specific definition of the relevant and available benchmarks, it may be necessary to convert the metrics used for characterising the performance of the technologies in the literature. For example, to relate efficiency gains from technology upgrades to the sectoral emission intensity pathways, it is most useful to provide data on efficiency gains from upgraded technologies in terms of reductions of GHG emissions intensity. With this information, a company could assess how a new technology contributes to its emission intensity reduction target and with which benchmark (or level of ambition) the resulting technology mix is in compliance.

What are the limitations when applying the scenario derived benchmarks to individual technologies and production pathways?

It is important to note that the existing scenario derived benchmark values currently only reflect aggregate values for:

- secondary and primary aluminium. As secondary aluminium is much less energy intensive than primary aluminium, the future share of secondary aluminium has a crucial influence on the aggregate benchmark values.
- existing and new facilities. The benchmark therefore reflects the share of primary production facilities that have been upgraded.

The average carbon intensity of a benchmark does not directly inform the evaluation of a specific investment. For example, an improvement of the average carbon intensity by 33% can be achieved either with a 33% improvement of all existing facilities, or with a 100% improvement of 33% of the production capacity of a firm. It is likely that only the latter approach will be compatible with a transition to net carbon neutrality. Therefore, it is crucially important that firms not only report their carbon intensity target for 2030, but in addition either:

- report the share of carbon neutral production in total production; or
- demonstrate otherwise the alignment of the measures/investments targeting emission reduction (and eventual "compliance" with the various sector pathways and scenarios) by 2030 with a credible path towards net carbon neutrality in 2050.

However, TPI and IEA benchmark values are only available until 2030. As investment decisions into new technologies have a longer lifetime, this is a relatively short timeframe which makes the benchmark values less relevant or even misleading when using them to determine technologies' or projects' "Paris compatibility". 2050 benchmarks, while sparsely available, are more relevant and need to be developed further for the different sectors. Moreover, it will be important to develop disaggregated benchmarks for primary and secondary production and for existing and new facilities.

Further issues to consider in relation to the use of scenario-based benchmarks

As discussed in section 3.3, the JRC follows a different approach than IEA and TPI. The JRC constructs energy consumption and GHG emission scenarios for the EU and Iceland until 2050 based on technological developments cost effectiveness, so the scenarios and benchmark values differ. Unfortunately, for aluminium only benchmark values for direct CO_2 emissions are given, making it difficult to compare them to IEA and TPI values.

It is also important to understand that only TPI takes greenhouse gases other than CO_2 into account. For aluminium, the values are expressed as CO_2 equivalents and include PFC-emissions, which explains the slightly higher values. JRC only takes PFC emissions for its baseline scenario into account.

ii) Management quality

The TPI has developed a method to capture the elements of governance, strategy and risk management, so that a company's management quality can be assessed. TPI highlights that a company's carbon performance is not necessarily indicative about a company's performance in the three management-related disclosure elements. For example, a company could have a carbon performance in line with the sectoral benchmark, but that does not imply the quality of its management around carbon-related issues be compliant to standards such as the TCFD. According to TPI, a poor management performance could imply that the company will not be able to stay compliant (Dietz et al., 2018).

Besides carbon performance, the TPI is therefore also reviewing a company's management quality. TPI bases its assessment on the approach of multiple initiatives, such as GRI, CDP, CDS and TCFD. TPI has developed a so-called 'Management Quality Framework' that places the management quality of companies on five levels, ranging from 'unaware' to 'strategic assessment'. The assessment is built on a set of 17 indicators (questions), the companies are categorized accordingly (Dietz, Garcia-Manas, Irwin, Rauis, & Sullivan, 2018).

iii) Required Disclosures

In order to ensure transparency for both scenario compatibility and management quality, a company is required to report and disclose elements important for assessing its carbon performance. There are multiple reporting frameworks, a detailed discussion can be found in Annex II.

For this study, especially the GRI standards on emissions (GRI 305), renewable energy (GRI 103, 302-1) and energy efficiency (GRI 103, 302-3, 302-4) are relevant. Similarly to the TCFD framework, the GRI specifically highlights disclosure of a company's management approach (GRI 103). The GRI standards for management disclosures are very extensive, they for example also include requirements for companies to report on the evaluation procedure of their management approach (GRI, 2018).

The emission reporting guidelines specified in section 305 outline requirements to report on scope 1, 2 and 3 GHG emissions (305-1, 2, 3) and how to report on emission intensity (305-4). GRI 305-5 also discusses reporting guidelines on GHG reductions (GRI, 2018).

The sections on renewable energy and energy efficiency (GRI 302-1, 302-2, 302-3, 302-4) further separate total energy consumption, e.g. by separating by energy consumed inside (GRI 302-1) and outside (302-2) the organization. Companies are required to disclose detailed reports of energy consumptions, e.g. split by fuel type. The GRI also requires a disclosure of energy efficiency (302-3), which is calculated by dividing the total energy consumption by the output metric of the company. Furthermore, GRI principle 302-4 outlines how companies should report on their energy efficiency improvements resulting from conservation efforts. Here, the company should also report on calculation method, including baselines, fuel types etc. (GRI, 2018).

The EU Technical Expert Group on Sustainable Finance (TEG) has set further reporting requirements for firms issuing green bonds. A firm shall e.g. report on compliance with the forthcoming EU Green Bond Standard, nature of green project and regional distribution (TEG, 2019). A full discussion of the reporting requirements proposed by the TEG can be found in TEG 2019, p. 40.

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Annex I – Further details on scenarios

Table 6: Overview of selected scenarios.

Scenario	Sectoral Carbon Budget	Technology Mix and Price Change	Transition Compliance
Short description	Global carbon budget is broken down into sectoral budgets that define carbon emission pathways for selected time periods	Sectoral roadmaps for a low-carbon future, different modelling approaches	Translation of climate roadmaps into scenarios used for modelling impacts on financial assets
Example	IEA (2017)	JRC for steel and aluminium (2012)	Transition risk-o-meter (2017)
In short: Modelling Approach	Based on socio-economic assumptions, historical trends, expert views and statistical information, exogenous material demand projections are used to determine the final energy consumption and direct CO_2 emissions of the sector, depending on the energy performance of process technologies and technology choice within each of the available production routes (IEA 2017, p.400)	Bottom-up models, prospective industry trends on an analysis at plant level of the cost-effectiveness of potential retrofits (BATs, ITs)	Model used for valuation of carbon risks build on existing frameworks, which are then expanded to include transition risk factors; functional relation of market dynamics and climate-related impacts on capital expenditure, operating cash flow and net margin is modelled
Main assumptions	Exogenous assumptions on the penetration and energy performance of best available technologies (BATs), constraints on the availability of raw materials, techno-economic characteristics of the available technologies and process routes, and assumed progress on demonstrating innovative technologies at commercial scale; assumptions on population and economic development	Exogenous assumptions on resource, electricity and CO_2 prices, demand/ consumption and production, the availability of materials/ technologies, implementation of BATs and ITs, data from production plants	Production, share primary/ secondary steel, carbon and energy intensity, resource prices, carbon price, share of free CO_2 allowances, technology development
Main sensitivities & limitations	- CO_2 budget very sensitive to changes in the probability (e.g. moving from 50% chance to limit temperature increase to 66% reduces carbon budget by 25%) - on assumptions how quickly physical capital is turned over, relative costs of technology options and fuels, on incentives for the use of BATs for new capacity (IEA 2017, p. 400) - Assumption on carbon budget: normative decision, sensitive to assumptions, problem of availability	- electricity price - capital cost, date of availability/emissions/ energy consumption of technologies - model is dependent on the disclosure of companies and the quality of supplied data	- consistency, missing indicators, continuity of sources, ease of access, coverage and costs

Annex II - Companies' disclosure and target setting

Four Elements of Climate-related Disclosure (TCFD)

In its "Recommendation Report" the TCFD proposes four fundamental elements that are to be disclosed by individual companies. The four thematic core elements are governance, strategy, risk management, and metrics and targets. The four disclosure elements are aligned with several other reporting frameworks, such as the G20/OECD Principles of Corporate Governance, the CDP Climate Change Questionnaire, the GRI principles, CDSB frameworks and the International Integrated Reporting Framework. A detailed overview of alignments with other organizations can be found in TCFD, 2017a.

1. Governance

Recognizing the risk and opportunities that come with climate-related issues, the TCFD believes that a company must have an internal governance structure designed to deal with such risks. A company is therefore required to disclose governance structures within the company's board, e.g. how they oversee climate-related matter. Moreover, a company needs to disclose how the company's management is concretely managing climate-related risks and opportunities (TCFD, 2017b).

2. Strategy

TCDF outlines that a company should make sure to directly link climate-related risks and opportunities to their business strategy as well as financial planning. Here, it is crucial to take both actual and potential impacts into account. TCFD outlines a step-wise approach for this disclosure process. First, companies are asked to identify short-, medium- and long-term risks and opportunities related to climate issues. Then, companies should disclose the expected impact on the business strategy and financial planning. Finally, the company should disclose how it is planning to cope with the identified risks. The company should hereby relate its resilience strategy to different climate and energy scenarios, e.g. to B2DS, 2DS and RTS. The TCFD specifically requires that the disclosure includes a strategy relating to B2DS scenarios (TCFD, 2017b).

For developing the company's strategy, TCFD recommends using scenario analysis. A company should demonstrate that the identified strategy is resilience when tested against different climate scenario. For this, the company is required to test its strategy against a range of scenarios. The strategy should further be tested under different key assumptions (e.g. policy scenarios, macroeconomic parameters) to demonstrate robustness (TCFD, 2017a).

In the material's sector, a disclosure about a company's strategy on the current and future use of innovative technologies (see section 4.1) is essential. Financial and strategic planning around the company's production facilities is central, as most new technologies require substantial amounts of capital. The TCFD highlights that specifically a company's strategy regarding R&DDD (research, development, demonstration, and deployment) is a crucial disclosure.

3. Risk Management

Under this theme, the TCFD requires company to disclose the internal procedures to identify, assess and manage risks and opportunities specific to their company. Here, a company is furthermore required to show how it is embedding the management of climate-related risks and opportunities into its risk management regarding other topics (Dietz, Garcia-Manas, Irwin, Rauis, & Sullivan, 2018). According to the 2018 TCFD status report, especially companies in the materials sector tend to disclose on risk management insufficiently (TCFD, 2018).

4. Targets and Metrics

When attempting to assess a company's carbon performance and compare it against benchmark scenarios, the disclosure of targets and metrics is especially important. Specific requirements regarding this topic will be discussed in detail in the subsequent section. An overview can be seen in Table 3.

TPI's approach to include TCFD elements 1-3

The TPI has developed a method to capture the disclosure elements of governance, strategy and risk management, so that a company's performance can be compared. TPI highlights that a company's carbon performance is not necessarily indicative about a company's performance in the three management-related disclosure elements. For example, a company could have a carbon performance in line with the sectorial benchmark, but that does not imply the quality of its management around carbon-related issues compliant to standards such as the TCFD. According to TPI, a poor management performance could imply that the company will not be able to stay compliant (Dietz, Garcia-Manas, Irwin, Rauis, & Sullivan, 2018).

Besides carbon performance, the TPI is therefore also reviewing a company's management quality. TPI bases its assessment on the approach of multiple initiatives, such as GRI, CDP, CDS and TCFD. TPI derives the data for the assessment from FTSE Russel, but lets the assessed companies cross-check during the quality control process.

TPI has developed a so-called 'Management Quality Framework' that places the management quality of companies on five levels, ranging from 'unaware' to 'strategic assessment'. The assessment is built on a set of 17 indicators (questions), the companies are places accordingly (Dietz, Garcia-Manas, Irwin, Rauis, & Sullivan, 2018).

GRI Reporting

The Global Reporting Initiative (GRI) Standards are another wide-used set of guidelines for companies for sustainability reporting. They are regularly updated by the Global Sustainability Standards Board (GSSB) and include guidelines to universal, economic, social as well as environmental topics (GRI, 2018). For this study, especially the GRI standards on emissions (GRI 305), renewable energy (GRI 103, 302-1) and energy efficiency (GRI 103, 302-3, 302-4) are relevant. Similarly to the TCFD framework, the GRI specifically highlights disclosure of a company's management approach (GRI 103). The GRI standards for management disclosures are very extensive, they for example also include requirements for companies to report on the evaluation procedure of their management approach (GRI, 2018).

The emission reporting guidelines specified in section 305 outline requirements to report on scope 1, 2 and 3 GHG emissions (305-1, 2, 3) and how to report on emission intensity (305-4). GRI 305-5 also discusses reporting guidelines on GHG reductions (GRI, 2018).

The sections on renewable energy and energy efficiency (GRI 302-1, 302-2, 302-3, 302-4) further separate total energy consumption, e.g. by separating by energy consumed inside (GRI 302-1) and outside (302-2) the organization. Companies are required to disclose detailed reports of energy consumptions, e.g. split by fuel type. The GRI also requires a disclosure of energy efficiency (302-

3), which is calculated by dividing the total energy consumption by the output metric of the company (see Table 3). Furthermore, GRI principle 302-4 outlines how companies should report on their energy efficiency improvements resulting from conservation efforts. Here, the company should also report on calculation method, including baselines, fuel types etc (GRI, 2018).

Principles of Reporting

While climate-related disclosure shall be in line with all TCFD principles for disclosure (TCFD, 2017a), principles 2 and 6 refer explicitly to scenario based and future-oriented information. Both the SASB and CSBD have very similar principles (SASB, 2017), a comprehensive overview of the alignment of different reporting principles can be found in CDSB 2018 p. 33.

TCFD's principle 2 stresses the requirement of reported data to be complete as well as specific. It states that companies should disclose on all climate relevant dimensions of the company according to the previously discussed four elements of disclosure. Disclosures must include historic data as well as future-relevant information where necessary. When disclosing information about the future, all key assumptions should be described in detail. Principle two further states that when scenario modelling is used, the underlying assumptions and data should be sound with the general financial and strategic planning of the company. A company is furthermore required to demonstrate how altering the key assumptions would affect the outcomes of the scenario modelling (TCFD, 2017b).

Principle 6 stresses the importance of reliability and objectiveness. Disclosed data should be as neutral as possible. This point is less straightforward for future projections, as assumptions have to made. Here, a company is required to base assumptions on objective data sources as much as possible (e.g. industry-wide standards), communicate the reasoning behind all judgements in detail and make sure all data is verifiable. For this process, it may be useful for company to orient this disclosure process on the already established financial disclosure processes of a company (TCFD, 2017a).

Discussion of Company Disclosure

The Transition Pathway Initiative (TPI) sees incomplete reporting as a major challenge. Without a comprehensive reporting, assumptions on certain parameters have to be made to apply the science-based target approach and accuracy is lost. In line with reporting frameworks of TCFD, CDP and GRI, companies should disclose 100% of their scope 1 emissions or, if not possible, should make a reasonable estimate on 100% of their scope 1 emissions. If they estimate emissions, they should report the proportion, the exact method and the reason why the data could not be collected. It should also be reported if and why scope 2 emissions cannot be calculated or estimated. They should further describe whether their target relates to scope 1 or scope 2 emissions. If they set an intensity target, they should report the estimated change in absolute emissions for each scope as a result of the intensity target. To be in alignment with the Paris Agreement, they may also set a 2050 target (EC, 2019a).