Carbon costs for the steel sector in Europe post-2020

Impact assessment of the proposed ETS revision – update June 2016

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Executive summary

In July 2015, the European Commission (EC) launched its proposal for a revised European Emissions Trading System (EU ETS) for the period after 2020. The resulting carbon costs to energy-intensive sectors, like the steel sector, are still poorly understood. As the carbon costs impact the competitiveness, the European steel sector is interested to get a better quantification of the carbon cost impact in the period 2021-2030. Commissioned by Eurofer, Ecofys developed the Ecofys' EU ETS Carbon Cost Calculator (E3C3) to assess future carbon costs under different scenarios. An important design criteria was to have all sources and assumptions as transparent as possible. With this model Ecofys provides the first transparent impact assessment of the EU Commission proposal for ETS revision post-2020

Based on our interpretation of the EC proposal, we found that the steel industry will face an annual shortage of allowances for direct emissions increasing from 32% in 2021 to 49% in 2030 (on average 38% over the period 2021-2030). Using carbon price projections of Thomson Reuters Point Carbon, this shortage can be expressed in net carbon cost rising from about €1.4 billion in 2021 to €4.8 billion in 2030. Cumulatively, the net direct carbon costs are calculated to be €27.1 billion for the period 2021-2030.

The sector is also highly exposed to indirect carbon costs passed through in electricity prices. Member States have the possibility to compensate companies for these costs. It was found that 37% of the indirect carbon costs would be covered by financial compensation over the whole decade, assuming that Member States that are granting or planning to grant compensation today will continue to do so in Phase 4. For the whole sector net carbon costs for indirect emissions would be €8.2 billion for Phase 4.

The total net carbon costs (for direct and indirect emissions) for the steel sector in the period 2021 – 2030 are projected to amount to €33.7 billion. This translates into €10/t crude steel in 2021 to €28/t crude steel in 2030.

Notes to the update of June 2016

The first version of this document, published in November 2015, served its purpose in providing transparency to the way the carbon costs for the steel sector were assessed. We had constructive discussions with several stakeholders, representing both authorities and third parties, which have led to this updated version. The main changes, incorporated in the main body of this document, relate to the following:

- Waste gas emissions: the list of installations combusting waste gases for the production of electricity has been refined based on a non-exhaustive validation step by Ecofys. Eurofer collected data on actual waste gas emissions based on actual waste gas transfer by the steel plants. These data were used by Ecofys after a sanity check.
- The list of Member States granting financial compensation for indirect carbon costs has been extended to include all Member States that do so per April 1st, 2016, or did so in the past.
- Production growth rates per sector were based on two stages, i.e. 2015-2020 and 2021-2030.

In addition, we added a sensitivity analysis in Annex I to assess the impact of the following parameters:

- Steel production growth rates that reflect those used by the EC, based on PRIMES.
- Benchmark flat rate for steel update based on -0.5% / a.
- The latest insights on carbon price projections.

We find that the carbon price has the largest impact, while still leaving net carbon costs to €6 / t crude steel in 2021 to €23 / t crude steel in 2030. This illustrates how margins can be impacted even under uncertain conditions.

In Annex II we added a calculation on the cumulative allowance balance in Phase 2 and Phase 3. We find that the steel sector is close to a net zero situation (between 11 MtCO_2 shortage and 19 MtCO_2 surplus) for the period 2008-2020.

1 Introduction

In July 2015, the European Commission (EC) launched its proposal for a revised European Emissions Trading System (EU ETS) for the period after 2020 (see Box 1). This marks the third step to structurally improve the functioning of the EU ETS after "backloading" and the introduction of the market stability reserve, which were adopted in previous years. As a result of these structural changes, market analysts expect carbon prices to rise significantly towards 2030, while the availability of free allowances for sectors exposed to risks of carbon leakage gets more limited, according to the ETS proposal.

The resulting carbon costs to energy-intensive sectors, like the steel sector, are still poorly understood: the European Commission's impact assessment accompanying their proposal is not completely transparent on this question and, more importantly, various options to distribute free allowances are still being discussed by the EU legislators, including a tiered carbon leakage approach. As the carbon cost impact the competitiveness, the European steel sector is interested to get insight in the following central question:

Based on the proposal by the Commission for a revised ETS, what carbon costs can the steel sector expect in the period 2021-2030?

In its proposal to revise the EU ETS for the period after 2020 the Commission proposes to continue current measures to compensate sectors at risk of carbon leakage. The most important features not changing compared to current rules are:

- free allocation is based on benchmarks for direct carbon costs and compensation for indirect carbon costs is to be granted via state aid from Member States;
- the total amount of free allocation is capped and will therefore require the existence of a cross-sectoral correction factor;
- a binary carbon leakage list is used, where sectors are "in" or "out".

The Commission also proposes several changes, the ones mostly affecting carbon costs are:

- benchmark values will be updated every 5 years based on a flat rate reduction factor between -0.5%/a and -1.5%/a;
- the carbon leakage status will be based on a combination of trade intensity and emissions intensity;
- activity levels will be updated every 5 years.

Box 1: The primary features of the Commission proposal for a revised ETS post-2020 affecting carbon costs

Ecofys was mandated by EUROFER to quantitatively research this question. Ecofys performed this assessment in order to create more transparency in the understanding of expected cost impacts, which we deem necessary for all stakeholders to make informed strategic and political decisions.

Disclaimer - *Ecofys took great care in validating all data that are used in the model. However, data that stem from EUROFER sources and from the BCG / VDEh Steel Roadmap could not be validated with the same rigidity as applied to the data from open sources. The validity of these data remains therefore the responsibility of EUROFER. In the Annex it is clearly indicated which data are from which sources.*

2 Key findings

The steel sector will face carbon costs as a result of two sources: 1) a shortage of allowances for direct emissions; and 2) from indirect costs passed through in electricity prices, for which no compensation is provided.

Figure 1 shows an annual breakdown for the direct CO_2 emissions and the amount of free allowances for the steel sector, based on the proposal by the European Commission. Emissions increase slightly because the efficiency increase (-0.12% / a) does not outweigh the increase in emissions stemming

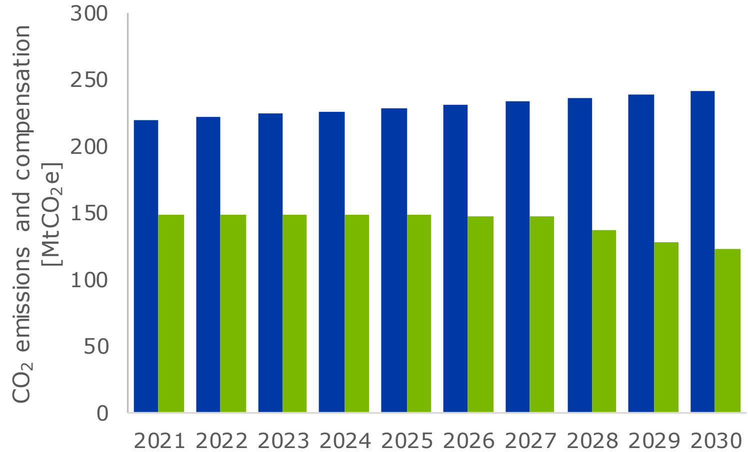


Figure 1: Projected total direct emissions (blue) and free allocation (green) for the steel sector

from the expected recovery of EU steel production after the economic crisis (+1.15% / a growth in production).

The difference between emissions and free allocation represents the annual shortage, which increases from 32% in 2021 to 49% in 2030 (on average 38% over the period 2021-2030). Such shortage is mainly caused by a combination

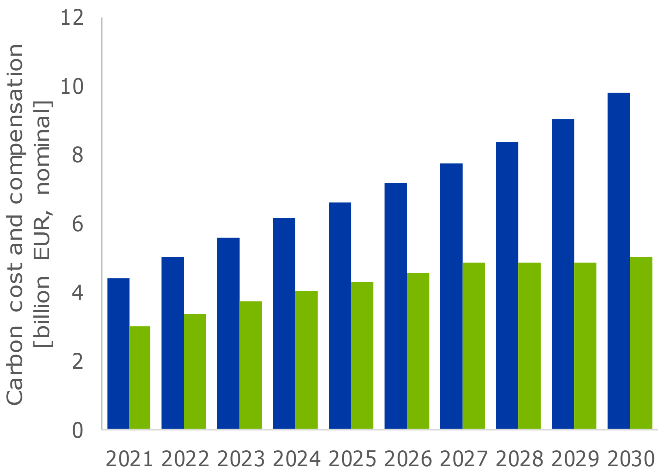


Figure 2: Gross direct carbon cost (blue) and value of free allowances (green) for the steel sector. The difference between the bars represents the net carbon costs.

of reduced benchmark values (linear reduction of 1%/year, i.e. -17.5% on average over the period 2021-2030) and the cross-sectoral correction factor, which is expected to be applied – in this scenario - in the last three years of the fourth trading period.

The shortage of free allowances leads to direct carbon costs (compliance cost for direct CO_2 emissions) for the steel sectors, which can be estimated using carbon price projections. This cost figure is based on a nominal carbon price of €20.1/t in 2021 progressively increasing to €40.7/t in 2030.[1]

Figure 2 shows the gross direct carbon costs and the value of free allowances for the steel industry. The increasing gross carbon costs is due to the increasing direct emissions of the sector and the projected increasing carbon price. The relative flat level of the value of free allocated allowances over the second part of Phase 4 is due to the combination of decreasing free allocation with increasing carbon price. The difference between the gross carbon cost and the value of free allowances represents the net direct carbon cost resulting from the emissions that are not covered by free allocation (shortage). The direct (net) carbon cost will be about €1.4 billion in 2021 and €4.8 billion in 2030. Cumulatively, the net direct carbon costs amount to €27.1 billion for the period 2021-2030.

[1] Source: Thomson Reuters Point Carbon (2015). See Annex 1 for a sensitivity analysis of changing the carbon price to more recent insights.

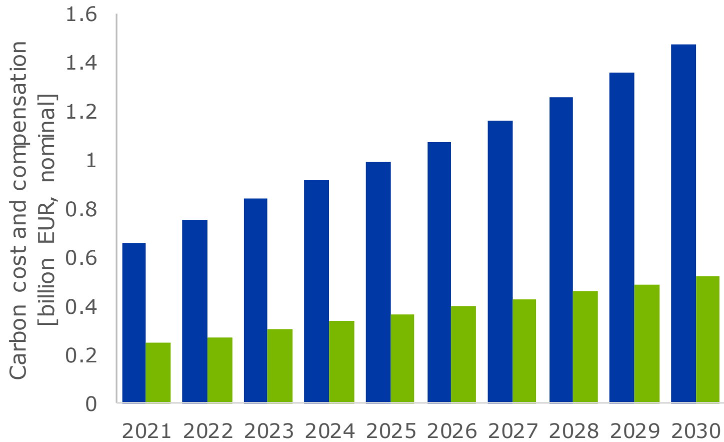


Figure 3: Projected indirect carbon cost (blue) and financial compensations (green) for the steel sector.

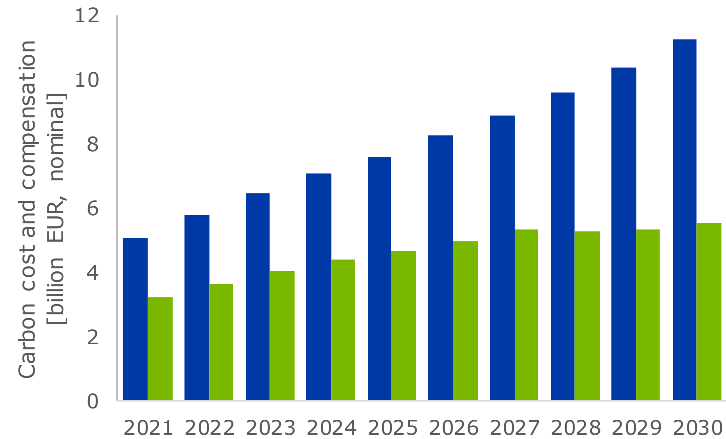


Figure 4: Projected total gross carbon costs (blue) and compensations (including free allocation for direct emissions and financial compensation for indirect costs) (green) for the steel sector.

Steelmaking is also electro-intensive, particularly the manufacture of recycled steel via Electric Arc Furnaces. This means that the sector is also highly exposed to indirect carbon costs passed through in electricity prices. Figure 3 shows the comparison between indirect carbon costs from electricity consumption and the financial compensation of these indirect costs if Member States that are granting or planning to grant compensation today are assumed to continue to do so after 2020.[2] In this scenario, the study finds that 37% of the indirect carbon costs would be covered by financial compensation over the whole decade.

Figure 4 shows the sum of the direct and indirect carbon costs of the steel sector. In the first year of the trading period (2021) about one-third of the

[2] Belgium, France, Germany, Greece, Lithuania, the Netherlands, Slovakia, Spain (to some extent in 2015 only), the UK, and Norway. This list is based on Member States for which there is official confirmation, either from the EC or from the Member State itself, that it will provide financial compensation per April 1st, 2016, or the Member State did so in the past (Spain).

carbon costs is not compensated (through free allocation for direct costs as well as financial compensation for indirect costs); in 2030 about half the carbon costs are not compensated. On average about 42% of gross carbon costs are not covered by free allocation and/or financial compensation over the whole decade.

The total net carbon costs for the steel sector in the period 2021 – 2030 are expected to amount to €33.7 billion, as summarized in Figure 5. The gross direct and indirect carbon costs of €80.3 billion consist of €69.8 billion direct and €10.5 billion indirect costs. The compensation granted of €46.6 billion consists of €42.7 billion of free allocation and €3.8 billion of financial compensation (based on current Member States continuing support).

The amount of carbon costs for the steel sector is robust for different updates of the benchmark values. If one assumes a lower benchmark reduction factor (-0.5% /a for all energy-intensive sectors), the model shows that the cross-sectoral correction factor would apply already in the first years of the trading period (2022) and reach the level of about 0.74 in 2030 (i.e. a 26% cut). However, the shortage in free allocation and the overall costs for the steel industry would be similar to the previous scenario as the more stringent cross sectoral correction factor would compensate the lower benchmark reduction ratio.

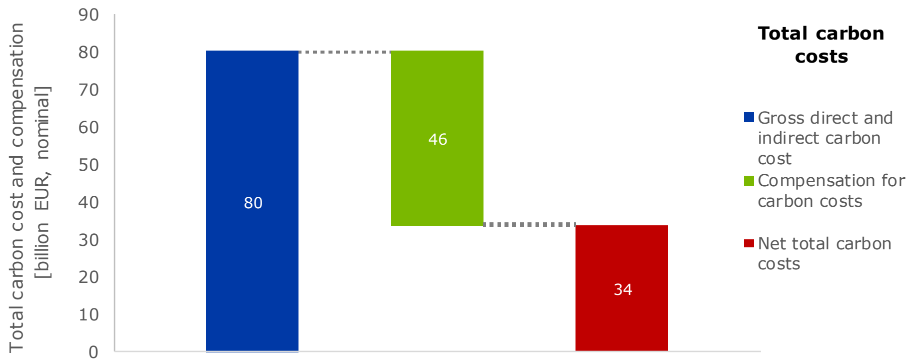


Figure 5: Total cumulative carbon costs for the steel sector in 2021 - 2030

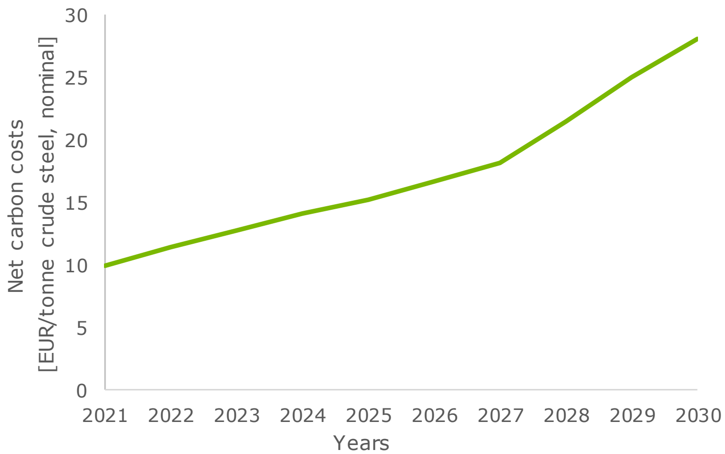


Figure 6: Projected net carbon costs (direct and indirect) per tonne of crude steel.

In order to have a better understanding of the relevance of such costs, the study analyses the impact of net carbon costs per tonne of crude steel. Figure 6 shows the evolution of net direct and indirect carbon costs in €/t crude steel over the period 2021 to 2030. The study finds that the steel industry will be faced with carbon costs from €10 / t crude steel in 2021 up to €28 /t crude steel by 2030 (average: €17 / t crude steel).

3 Our approach

To answer the question at hand, Ecofys developed the *Ecofys' EU ETS Carbon Cost Calculator* (E3C3) which compares future emissions with compensation levels for different sets of compensation scenarios. The model consists of different building blocks to determine direct and indirect carbon costs[3] (see Figure 7). The modular approach allows to flexibly change input parameters, if needed, and to toggle easily between scenarios.

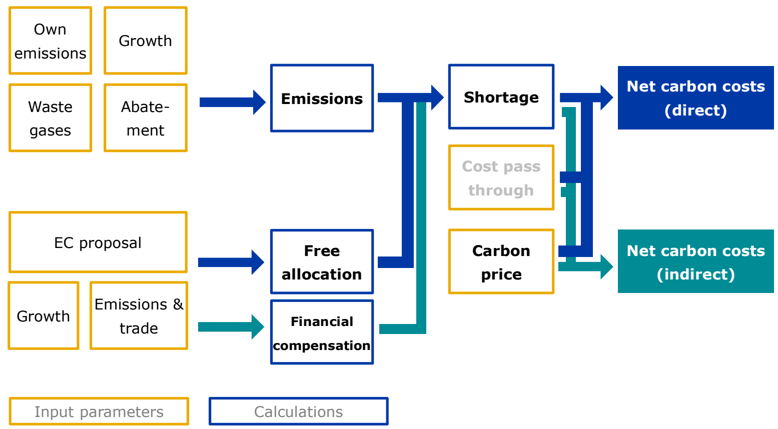


Figure 7: Schematic overview of Ecofys' E3C3 model to determine carbon costs

Under the assumption of zero cost pass-through[4], net carbon costs are defined as the difference between total emissions and compensation levels (free

[3] Direct carbon costs come from the obligation to cover GHG emissions (either on-site or exported in waste gases) with corresponding allowances, indirect carbon costs stem from carbon costs passed through in electricity prices.

[4] The cost pass-through ability has not been assessed in this study. Nevertheless, an assumption of zero cost pass-through is taken to show the net carbon cost exposure to sectors.

allocation and/or financial compensation) multiplied by the carbon price. We will now zoom into the first two elements.

Emissions

Direct emissions in the steel sector have been forecasted by taking emissions in a baseline year (2014) and applying an annual production growth rate and abatement rate, both taken from the Steel low-carbon roadmap developed by BCG/VDEh[5].

For **direct emissions** Ecofys took verified emissions as reported in the public European Transaction Log (EUTL) database for ETS installations that were identified as belonging to the steel sector (see Box 2) for a definition of the sectoral scope). In addition, emissions from the combustion of recovered waste gases for electricity production outside the steel industry were added, as steel plants pay for these downstream emissions by means of allowances and/or higher electricity prices. The waste gas plants were identified by Eurofer and validated by Ecofys, by linking each waste gas plant to a corresponding steel plant. Next, actual waste gas emissions were collected by Eurofer for the years 2008-2014, based on actual waste gas transfer by the steel plants. These data were used by Ecofys after a sanity check, e.g. by comparing the waste

The **scope of the steel sector** has been defined as a list of 437 ETS-installations performing relevant steel sector activities. The list was derived from a long list of 620 installations selected by combining installations that report under steel-related ETS activities (3, 4, 5, 22, 23, 24, and 25 in EUTL) and relevant NACE codes (07.10, 19.10, 24.10 and 24.20). From this long list 112 installations were excluded by EUROFER as they were not recognized as part of the steel sector (i.e. forges, foundries, and installations producing non-ferrous metals, chemicals, or ferroalloys), and 71 installations were found to be closed.

Box 2: Scope of the steel sector

emissions with EUTL data from waste gas plants and correcting for any possible double counting. Due to data sensitivities not all companies could reveal the split between direct and indirect emissions in waste gas emissions and therefore they were all accounted as direct emissions. To avoid double counting, indirect carbon costs in the corresponding steel production process (the blast furnace route) are excluded from the analysis.

[5] Boston Consulting Group and the Steel Institute VDEh (2013). Steel's contribution to a low-carbon Europe 2050.

The calculation of **indirect carbon costs** is slightly more detailed, as it relies on two production routes within Electric Arc Furnaces (EAF carbon steel and EAF high alloy steel) and should be differentiated per country. We used verified values of the average electricity intensities of EAF carbon steel and EAF high alloy steel and multiplied this with the production forecast for each of these routes. In addition, electricity use from downstream processes (rolling) were added based on the electricity intensity derived from BREF documents.

The **production growth rate** of the steel sector until 2030 has been set at 1.15%/year where the 2030 production volume corresponds to the one from the Steel low-carbon roadmap[6]. This growth rate has been used to project direct emissions. For indirect carbon costs, a more specific EAF steel growth rate per country has been derived, based on the assumptions that the EAF share in the total steel production increases by 0.18% per year[7], the EAF share per country stays constant and the split between EAF carbon steel and EAF high alloy steel also stays constant.

The **abatement rate** of the steel sector has been set at -0.12%/year for specific direct emissions and -0.26%/year for specific electricity consumption, based on the Steel Low-carbon Roadmap. The value for the direct emissions includes the impact of a shift between the EAF and BF/BOF steel production, energy efficiency improvements, fuel mix changes, and production growth and excludes the impact of the grid emission intensity improvement on the annual carbon efficiency improvement rate.

Free allocation

The amount of free allocation can in principle be determined in quite a straightforward way as depicted in below equation.

Free allocation =

Benchmark x Historical activity level x CL factor x Cross sectoral correction factor

However, as activity levels are not available for the relevant steel benchmarks, and to stay consistent with the approach for emissions, allocation is determined by taking allocation in a baseline year (2014) and project this towards the future using forecasted production growth. This approach is applied to each steel production route separately. As reference years we use the median of the

[6] The projections from BCG and VDEh estimate that the crude steel production in the EU27 (173 Mt in 2010) will grow to 204 Mt in 2030, but will still remain below pre-crisis levels (211 Mt in 2007). See Annex I for a sensitivity analysis on the impact of the production growth.

[7] The increase of the EAF share of 0.18% per year is in line with the projections of BCG and VDEh that estimate an EAF share of 41% in 2010 progressively increasing to 44% in 2050.

production in 2013 – 2017 and 2018 – 2022, respectively, for the two allocation periods after 2020 as suggested by the European Commission.

The **carbon leakage list** and related compensation factors are derived from the Impact Assessment from the European Commission. For the steel sector NACE codes, a compensation factor of 100% is assumed.

The **cross-sectoral correction factor** follows from a detailed analysis at sectoral level. The correction factor kicks in if the bottom-up free allocation to all industrial ETS installations exceeds a top-down cap on free allocation. The cap on free allocation is 6,267 million allowances for the period 2021 -2030. The bottom-up allocation demand is the sum of the allocation need for steel, cement, refineries, basic chemicals and other industries and depends on three factors: activity levels (based on historical data from public sources and forecasts derived from PRIMES data), updated benchmark levels (variable input parameter), and the carbon leakage compensation factor per NACE sector. In our default scenario, the latter two parameters are based on the EC Impact Assessment complemented with Ecofys analysis.

Financial compensation

The European Commission has not indicated how the maximum compensation for indirect carbon costs should be calculated after 2020. The current compensation guidelines heavily build on the rules for free allocation for direct emissions, with the only main difference being the production baseline calculation methodology. Given that the EU is aiming for increased harmonisation of rules, Ecofys assumes that the calculation methodology for the production baseline and benchmark update will be in line with the free allocation approach. The model assumes that Member States currently granting or planning to grant financial compensation[8] will continue after 2020 with a state aid intensity at 75%. Marginal emission factors are assumed to have decreased by about 8 – 12% based on PRIMES.

[8] See footnote 2.

Annex I: Sensitivity analysis

The projected carbon costs to the steel sector depends on several assumptions, like the sectoral growth rate, the flat rate benchmark update, and the projected carbon price. The sensitivity to these assumptions have been checked, and the results are presented in Table 1.

The following sensitivity checks (all else being equal) are carried out:

- **Scenario 1:** Sectoral growth rate for the steel sector is assumed at +0.64% / a, based on PRIMES (compared to 1.15% / a in the base case scenario).
- **Scenario 2:** The benchmark flat rate for the steel sector is put at -0.5% / a, reflecting a limited efficiency improvement (compared to -1.0% / a in the base case scenario).
- **Scenario 3:** The (nominal) carbon price is based on the latest projection from Thomson Reuters Point Carbon (March, 2016)[9].

Table 1: Carbon costs to the steel sector under several scenarios

	Base case	Scenario 1	Scenario 2	Scenario 3
Net total carbon costs in 2021-2030 (in billion)	€33.9	€29.8	€31.5	€23.2
Annual shortage in '21	32%	30%	26%	32%
Annual shortage in '30	49%	46%	45%	49%
Net costs per tonne of crude steel in '21 – '30	€10 to €28	€9 to €26	€8 to €26	€6 to €23

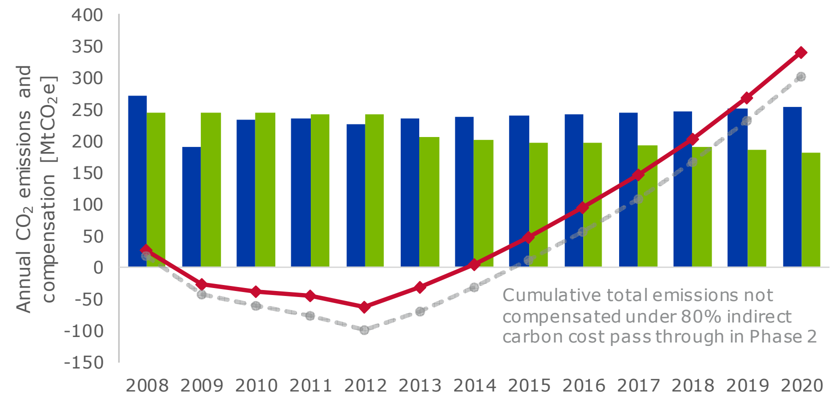
[9] Thomson Reuters Point Carbon (2016). Nominal carbon price projections of €12 / t in 2021 to €33 / t in 2030.

Annex II: Cumulative impact of EU ETS Phase 2 and 3

This appendix presents the expected cumulative impact of the EU ETS on the steel sector in Phase 2 (2008-2012) and Phase 3 (2013-2020).

During Phase 2, the EU ETS was based on national emissions reduction caps. Free allocation was granted according to historical emissions with a different allocation methodology in each Member State. No financial compensation for indirect carbon costs was provided. With the beginning of Phase 3 in 2013, major changes have been introduced: a single EU-wide cap is applied and free allocation is based on a harmonized benchmarking approach, reflecting the average emission performance of the 10% most efficient installations. Member States may compensate part of indirect carbon costs passed through in electricity prices, and so far a limited number of Member States are doing so.

For the amount of waste gas emissions, Ecofys used actual data for waste gas emissions (coming from both coke plants and BF/BOF installations) collected by Eurofer for the years 2008-2014. The 34 identified waste gas installations showed an overall share of 87% of CO_2 from waste gases in their total reported CO_2 emissions. The waste gas emissions and allocations are treated differently in Phase 2 and 3 due to differences in rules. For Phase 2, only waste gas

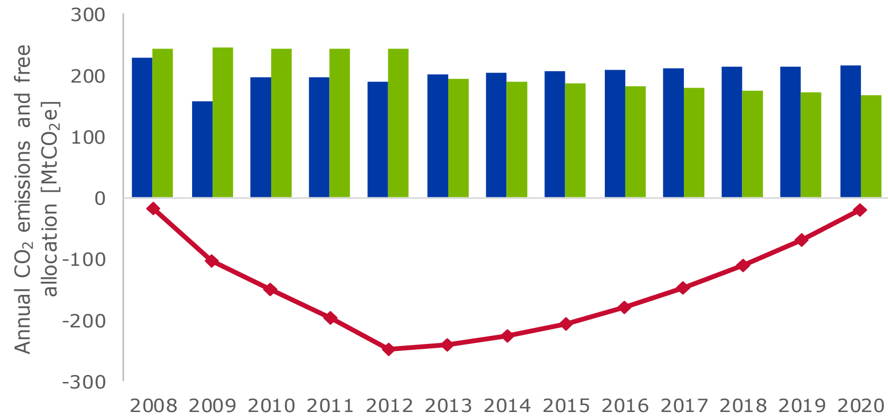


A. 1: Projected total gross carbon costs (blue) and compensations (including free allocation for direct emissions and financial compensation for indirect costs) (green) for the steel. The red line indicates the cumulative shortage in the steel sector for both direct and indirect costs (negative value is surplus). The grey line shows the total carbon costs not compensated if power producers passed through 80% of their gross carbon costs in Phase 2.

emissions are taken into account for which the steel plant receives free allocation. If the waste gas installation receives the allocation, 0% of the waste gas emissions (and allocations) are taken into account. This was the case for Czech Republic, Poland, Romania, and 25% of the Netherlands.

Figure A.1 presents the cumulative impact of direct emissions not covered by free allocation and indirect carbon costs (expressed in CO_2 equivalent) not compensated over the period 2008-2020. Costs equivalent to 48 $MtCO_2e$ are not covered by free allocation and financial compensation in 2015 and by 2020 such costs will increase to an equivalent of 352 $MtCO_2e$.

In Phase 2 installations received free allocation for the emissions from power production. Various studies have shown that power producers nonetheless passed on the gross carbon costs[10] from electricity with a rate near or above 100%[11,12], with a carbon cost pass through rate for power producers found at least 84% in Germany[13]. To account for a scenario where the power producers did not fully pass on their carbon costs as they received free allocation, the grey line in Figure A.1 shows the total carbon costs not compensated under a cost pass through rate for power producers of 80% for the indirect carbon costs in Phase 2. This shows that even assuming limited cost pass through of carbon costs through the electricity price, costs equivalent to more than 300 $MtCO_2e$ are not covered by free allocation and financial compensation in 2020.



A. 2: Gross direct carbon costs (blue) and free allowances (green) for the steel sector in 2008-2020 in $MtCO_2e$. The difference between the bars represents the annual shortage in emission allowances. The red line indicates the cumulative shortage in the steel sector for direct costs only (negative value is surplus).

[10] Also referred to as opportunity costs, i.e. the costs of not selling the allowances received for free.

[11] Fell, H., Hintermann, B., & Vollebergh, H. R, 2013. Carbon Content of Electricity Futures in Phase II of the EU ETS. Technical Report 2367, CESifo Working Paper.

[12] Laing, T., Sato, M., Grubb, M. and Comberti, C. (2014), The effects and side-effects of the EU emissions trading scheme. WIREs Clim Change, 5: 509–519.

[13] Hintermann, B, 2014. Pass-through of CO_2 Emission Costs to Hourly Electricity Prices in Germany. CESifo Working Paper No. 4964.

Figure A.2 presents the comparison between direct emissions and free allocation over the period 2008-2020. The second trading period experienced an overallocation as a result of falling production levels due to the crisis, combined with the ex-ante free allocation rules. However, during the third trading period the steel industry is short in free allowances every year, with the annual shortage of free allocation growing over time. As a result, the historical overallocation steel sector is gradually reduced and the steel sector will be in shortage from the start of the fourth trading period.

This analysis assumes 1) an annual production growth of +1.15% / a from 2015 onwards (actual data are used for 2008-2014); 2) any surpluses accrued over time are available for the steel sector for later use. These may not be valid assumptions in case steel plants go through insolvency or bankruptcy. In such a situation surplus allowances need to be sold in order to satisfy the creditor or fulfil financial obligations and are not available to the rest of the sector. It also implies that European production may be lower than projected. Both effects are reviewed here.

Recently, the steel sector has experienced several cases of closures:

1) SSI Redcar Steelworks in Teesside (UK) entered liquidation in October 2015 and have ceased all activities in Europe.[14] The corresponding installation identifiers GB330 and GB1263[15] built up a cumulative surplus of 15.5 Mt in the period 2008-2014. The SSI group does not hold other steel plants under the EU ETS.
2) Carsid / Duferco stopped their BF / BOF activities in 2012, after not being in operation since 2010. The affected installations (with IDs BE284, BE285, BE286, BE287, BE288) accumulated a surplus of 14.8 Mt over the period 2008-2012. According to various sources in the media, the company sold these surplus allowances to cover unemployment expenses.[16]

In addition, Europe faces other significantly under-utilized BF / BOF steel plants, some of which are declared insolvent (e.g. Lucchini Piombino and Ilva Taranto). It is unclear yet whether this leads to (compulsory) sales of their surplus allowances, therefore these cases are not considered here. Other installations that have closed in reality are also not specifically considered, creating a conservative estimate.

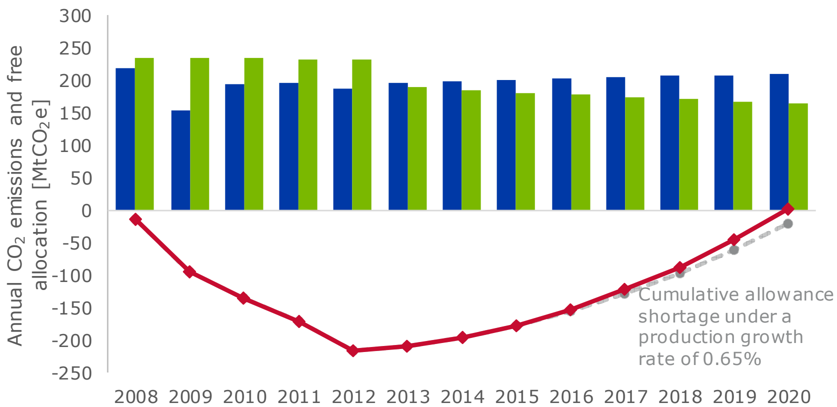
Taking into consideration the unavailable surplus from the two aforementioned cases, about 30 MtCO_2 in total, the small cumulative surplus projected by 2020

[14] Source: http://www.bbc.com/news/uk-england-34509329

[15] These numbers refer to the installations' identification number in the EU ETS used in the EUTL.

[16] See for example: https://www.rtbf.be/info/economie/detail_carsid-duferco-avait-obtenu-des-quotas-de-co2-pour-payer-les-travailleurs?id=7738903

turns into a small shortage (11 $MtCO_2$). If the two closed plants are taken out of the analysis (i.e. both direct emissions and allocations are set to zero), again a small shortage is experienced cumulatively by 2020, as depicted by the red line in Figure A. 3. As a sensitivity check, a lower growth rate of +0.65%/a has been tested. This would lead to a limited cumulative surplus by 2020, indicated by the grey line, which would imply the steel sector would be short from 2021 onwards.



A. 3: Gross direct carbon costs (blue) and free allowances (green) for the steel sector in 2008-2020 in $MtCO_2e$, with two closed steel plants taken out of the analysis. The red line indicates the cumulative shortage in the steel sector for direct costs only (negative value is surplus). The grey line shows the cumulative surplus in case of a lower growth rate (+0.65%/a).

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Annex III: Overview of input parameters, values and assumptions

General E3C3 model parameters

Parameter	Value chosen	Source
Benchmarks [tCO_2/tonne]	Hot metal: 1.328 Coke: 0.286 Sintered ore: 0.171 EAF carbon steel: 0.283 EAF high alloy: 0.352	EC Decision 2011/278/EU
Benchmark heat Phase 3 [tCO_2/TJ]	62.3	EC Decision 2011/278/EU
Benchmark fuel Phase 3 [tCO_2/TJ]	56.1	EC Decision 2011/278/EU
Benchmark basic oxygen steel [MWh/t product]	0.036	EC Communication 2012/C 387/06
Fallback benchmark for indirect carbon cost compensation [%]	80%	EC Communication 2012/C 387/06
Heat-electricity exchangeability factor [%]	EAF carbon steel: 28% EAF high alloy: 25%	EUROFER data
Heat benchmark phase 4 [tCO_2/TJ]	53.0	EC SWD(2015) 135 final, p.191
Marginal electricity grid factor [tCO_2/MWh]	Series (2008-2030) per country	2008-2020: EC Communication 2012/C 158/04 2021-2030: Ecofys calculations based on PRIMES data, 2021-2030 average of linear converging marginal grid factors (starting from EC Communication 2012/C 158/04) from 2021 onwards to 2050.
Average electricity grid factor [tCO_2/MWh]	0.465	EC Decision 2011/278/EU
Cross sectoral correction factor [%]	Series (2013-2020)	EC Decision 2013/448/EU
Linear reduction factor	Series (2013-2020)	EC Directive 2003/87/EC
Carbon leakage exposure factor	Series (2013-2020)	EC Decision 2011/278/EU
Industry allocation cap 2013 [EUA]	809,315,756	EC Decision 2011/278/EU
Final allocation heat production 2013 [EUA]	104,326,872	EC Decision 2013/448/EU

Parameter	Value chosen	Source
CL share in allocation for heat production	27%	Ecofys calculations based on PRIMES data
Total ETS cap excl. aviation [$MtCO_2e$]	Series (2021-2030)	EC Decision 2010/634/EU
Auctioning share in cap [%]	57%	EC Communication COM/2015/0337
Innovation fund (NER400) [million EUA]	400	EC Communication COM/2015/0337
Degree of compensation for indirect carbon costs granted [%]	Series (2013-2020) and for Phase 4 per country	Ecofys analysis
Maximum state aid intensity [%]	75%	Ecofys assumption
Carbon price [€/tCO2]	Series (2012-2030)	ThomsonReuters Point Carbon, EU ETS Phase 4 Proposal: learning to share, p. 7

Parameters specific to the steel sector

Parameter	Value chosen	Source
Baseline year for projections	2014	The latest year for which all production, emissions and allocation data is available
Crude steel production [thousand tonnes crude steel]	Series (2005-2014) per country	Worldsteel - Steel statistical yearbook 2014 (Tables 7-9), Monthly crude steel production Jan-Jul 2015 vs 2014
Annual production growth rate [%]	1.15%	BCG/VDEh - Steel's contribution to a low-carbon Europe 2050, p. 32.
BF/BOF steel conversion factors [tonne per tonne BF/BOF steel] Downstream fuel consumption in [GJ per tonne BF/BOF steel]	Hot metal to BF/BOF: 0.901 Coke to BF/BOF: 0.344 Sintered ore to BF/BOF: 1.44 Downstream fuel: 1.8	EUROFER, based on investigation of BREF documents
EAF steel production [thousand tonnes crude steel]	Series (2005-2014) per country	For 2005-2013: Worldsteel - Steel statistical yearbook 2014 (Table 8). For 2014: World Steel in Figures 2015 Crude Steel Production by process 2014
EEA-wide EAF share projection [%]	From 41% in 2010 to 44% in 2050	BCG/VDEh - Steel's contribution to a low-carbon Europe 2050, p. 16.
Share of EAF carbon and high alloy steel [%]	EAF carbon: 80.67% EAF high alloy share: 19.33%	EUROFER - 2015 edition European Steel in Figures, page 6. Average 2012-2014
Annual carbon efficiency improvement rate [%]	-0.12%	Interpolation based on BCG/VDEh - Steel's contribution to a low-carbon Europe 2050, p. 15
Electro-intensity [kWh/tonne]	EAF carbon: 569.7 EAF high alloy: 703.3 Downstream: 137.2	EAF: EUROFER data Downstream: EUROFER findings in the BREF documents
Annual electro-intensity improvement rate, baseline year	-0.26% starting from 2008	BCG/EUROFER data
Emissions of steel plants [$MtCO_2e$]	Series (2008-2014); 161.0 $MtCO_2$ in 2014	EUTL (Ecofys download June 2015), based on selection of installations by EUROFER (441 open, 71 closed installations)

Parameter	Value chosen	Source
Emissions of waste gas plants [$MtCO_2e$]	Series (2008-2014); 43.2 $MtCO_2$ in 2014	Based on selection of EUTL installations and data collection by EUROFER (28 open. 6 closed installations)
Allocation to steel plants [$MtCO_2e$]	Series (2008-2020); 189.8 $MtCO_2$ in 2014	EUTL (Ecofys download June 2015), based on selection of installations by EUROFER (441 open, 71 closed installations)

Parameters related to carbon leakage

Description	Value chosen	Source
Compensation factors EC proposal, July 2015	Very high: 1 Low: 0.3	EC Communication COM/2015/0337, July 2015
Compensation factors EC IA, "Limited changes" package, July 2015	Very high: 1 High: 0.8 Medium: 0.6 Low: 0.3	EC SWD(2015) 135 final (Impact Assessment), July 2015
Compensation factors EC IA, "Targeted" package, July 2015	Very high: 1 High: 0.8 Medium: 0.6 Low: 0.3	EC SWD(2015) 135 final (Impact Assessment), July 2015
CL tier thresholds EC proposal, July 2015 (emission intensity x trade intensity)	Very high: 0.2 Low: 0	EC Communication COM/2015/0337, July 2015
CL tier thresholds EC IA, "Limited changes" package, July 2015	Emissions intensity => Very high: 9, High=2, Medium: 0.2, Low:0 Trade intensity => Very high: 0.2, High=0.1, Medium: 0, Low:0	EC SWD(2015) 135 final (Impact Assessment), July 2015
CL tier thresholds EC IA, "Targeted" package, July 2015 (emission intensity x trade intensity)	Very high: 2.5 High: 1 Medium: 0.2 Low: 0	EC SWD(2015) 135 final (Impact Assessment), July 2015
Emission intensity and trade intensity per NACE sector [%]	Series	EC, Detailed data on direct and indirect costs, and trade, for all assessed sectors. 22 May 2014 + Ecofys analysis

Parameters related to the cross-sectoral correction factor

Description	Default value chosen	Source
Annual improvement factor benchmark	Cement (2021-2025): -0.5% Cement (2026-2030): -0.5%	EU Commission, impact assessment July 2015 proposal, p.142 and p.176
Annual improvement factor benchmark	Refineries (2021-2025): -1% Refineries (2026-2030): -1% Basic chemicals, incl. fertilizers (2021-2025): -1.5% Basic chemicals, incl. fertilizers (2026-2030): -1.5%	EU Commission, impact assessment July 2015 proposal, p.142 and p.177
Annual improvement factor benchmark	Other industry (2021-2025): -1% Other industry (2026-2030): -1%	EU Commission, impact assessment July 2015 proposal, p.142 and p.178
Allocation phase 3	Cement: 1,110,105,321 tCO_2 Refineries: 878,402,084 tCO_2 Basic chemical, incl. fertilizers: 998,567,590 tCO_2	EU Commission, Questions and Answers on the Commission's decision on national implementation measures (NIMs)
Annual production growth rate (2015-2020)	Cement: 1.34% Basic chemical, incl. fertilizers: 1.72%	Based on PRIMES EU28 data, average 2010-2020 and 2020-2030 annual growth rate sector value added
Annual production growth rate (2021-2030)	Cement: 1.22% Basic chemical, incl. fertilizers: 1.12%	
Annual production growth rate (2015-2020)	Refineries: -0.90%	PRIMES EU28 data on fuel input into refineries
Annual production growth rate (2021-2030)	Refineries: -0.50%	
Production growth rate (2015-2020)	Other industry: 1.17%	Ecofys estimate. Based on PRIMES EU28 data, average 2010-20 and 2020-2030 annual growth rate sector value added excluding the sectors evaluated separately
Production growth rate (2021-2030)	Other industry: 1.03%	
Production index other industry	Series (2005-2014)	Eurostat, production in industry – monthly data
Production index cement	Series (2005-2013)	GNR Project, Total production volumes of clinker, http://www.wbcsdcement.org/GNR-2013/EU28/GNR-Indicator_8TG-EU28.html
Production index refineries	Series (2005-2014)	BP Statistical review of World Energy 2015
Production index basic chemicals	Series (2005-2013)	CEFIC Facts and Figures 2014, chart 3.4
Production index non-ETS heat	Series (2005-2013)	Eurostat Energy Statistics