Assessment of the potential for carbon leakage in Phase IV of the EU ETS

Synthesis Report

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Contact: CLIMA-B02-ARES@ec.europa.eu

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Sean Healy (Öko-Institut)

Verena Graichen (Öko-Institut)

Hans Bolscher (Trinomics)

Matthew Smith (Trinomics)

Marwa Mahmoud (Trinomics)

Tycho Smit (Trinomics)

Chris Green (Ricardo)

William Acworth (Adelphi)

Chris Kardish (Adelphi)

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1. INTRODUCTION

The Paris Agreement aims to reduce greenhouse gas (GHG) emissions in order to limit the rise of the 'global average temperature to well below 2ºC above pre-industrial levels' (UNFCCC 2015b). It was, however, further acknowledged in the Paris Agreement that limiting the temperature increase to 1.5ºC above pre-industrial levels 'would significantly reduce the risks and impacts of climate change' (UNFCCC 2015a). Indeed, a subsequent IPCC (2018) report on the impacts of global warming of 1.5ºC above pre-industrial levels suggested that:

- There are robust differences in regional climate characteristics between present day[1] and global warming of 1.5°C and 2°C' and;
- Global emissions will need to reach net zero by 2050 if global warming is to be limited to 1.5°C above pre-industrial levels.

The findings from the IPCC (2018) report led the EU to review the ambition of its Nationally Determined Contribution (NDC) to the Paris Agreement[2] and subsequently the European Commission announced the European Green Deal in December 2019, which proposes to raise the ambition level of the EU's GHG reduction target for 2030 to at least 55 % below 1990 levels (European Commission 2020b). This represents a substantial increase compared to the existing target of at least 40 % and this has far-reaching implications for industrial sectors in Europe that will now be required to decarbonise and reach carbon neutrality by 2050. Given that the EU Emissions Trading System (ETS) is the key instrument for reducing GHG emissions from power and industrial sectors, there is a concern from industry that this enhanced level of ambition will lead to an increase in direct and indirect CO_2 costs that may undermine their international competitiveness and result in carbon leakage.[3]

Indeed, the EU allowance (EUA) price has increased considerably in recent years (albeit from a relatively low base) prior to the announcement of the European Green Deal due to a package of reforms that had already been agreed for Phase IV of the EU ETS (EU 2018). For example, the ETS cap had been adjusted downwards by increasing the Linear Reduction Factor (LRF) to 2.2 % from 2021 onwards so that the EU ETS could reduce its emissions by 43 % relative to 2005 levels by 2030. To reach the enhanced level of ambition announced recently in the European Green Deal it is expected that the ETS cap will have to be further reduced, but the contribution of the EU ETS towards this target (and the timing of any further adjustment to the ETS cap) is yet to be determined. The reforms for Phase IV also included the strengthening of the Market Stability Reserve (MSR)[4] by doubling the amount of allowances that will be put into the reserve between 2019 and 2023 and from 2023 onwards the number of allowances held in the MSR will be limited to the auction volume of the previous year. This will have the effect of tightening the cap and thus raising the ambition.

To limit the risk of carbon leakage, it was agreed within the revision to Phase IV of the EU ETS to continue to provide free allowances to industry with those sectors deemed at risk of carbon leakage receiving 100 % of their allocation up to the relevant benchmark for free. The benchmark values for calculating the level of free allocation given to each installation will be updated twice during Phase IV in order to reflect technological progress since 2008.

The main objective of this study was to provide an estimate of the availability of free allowances in Phase IV for the major emitting industrial sectors under different ETS cap scenarios and to then subsequently identify any potential shortage in allowances

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1 Human activities are estimated to have so far caused approximately 1.0°C of global warming above pre-industrial levels.

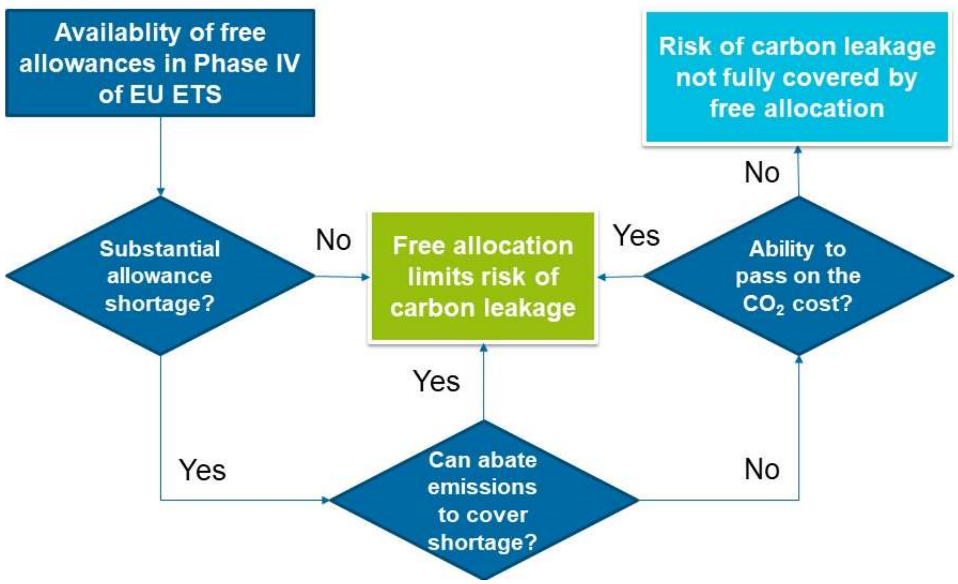
2 NDC refers to measures set by each country to contribute to the achievement of the Paris Agreement.

3 Refers to the situation that may occur if, for reasons of costs related to climate policies, domestic products were replaced by more carbon-intensive imports. This could lead to an increase in global GHG emissions.

4 The MSR is a quantity-based mechanism that aims to control the volume of EUAs in circulation to ensure the price signal of the EU ETS is more robust to external shocks.

relative to their direct emissions (refer to Section 2). The framework[5] illustrated in Figure 1-1 then provides a series of further steps that can be followed to assess the vulnerability of an industrial sector to carbon leakage. Section 3 focuses on the abatement potential of the major emitting industrial sectors to assess the extent to which any shortage of allowances expected in Phase IV could be reduced via the implementation of options to reduce emissions. Assuming that not all of the shortage of allowances can be offset by emission reductions at a reasonable cost,[6] Section 4 focuses on the ability of sectors to pass on their CO_2 costs based upon specific characteristics relying upon key indicators. Section 5 will then discuss alternative options for protecting against carbon leakage where the assessment suggests that the risk of carbon leakage is not likely to be fully covered by free allocation.[7]

Figure 1-1 Overview of approach for assessing the vulnerability of sectors to carbon leakage in Phase IV of the EU ETS



Source: Own illustration.

Projecting into the future is always associated with a high degree of uncertainty and this has been further exacerbated by the emergence of the Covid-19 crisis over the course of this study. Depending upon the timeline for a recovery from the economic impacts of the pandemic, this may require the projections on activity rates assumed within this study for European industry to be updated in future assessments. It was beyond the scope of this study to assess different EUA price projections caused either by changes in demand or by adjustments to supply. The extent to which any potential shortage in free allowances estimated in this assessment could be covered by implementing abatement options at a reasonable cost was therefore not possible to determine. However, the first order assessment of abatement potential by industrial sector nevertheless provides insights into what is theoretically possible. The extent to which these options will be financially viable over the next decade will depend upon market fundamentals, technological innovation and targeted financial support.

[5] This is a simple logic framework that was followed within the project; however, it is acknowledged that in reality the situation is more complex. For example, the ability of a sector to pass on the CO_2 cost may increase its profitability enabling an increase in investments in abatement options.

[6] Reasonable cost is a term that is difficult to define and is likely to vary from one sector to another depending upon their circumstances. In our framework, the term refers to abatement options whose costs are equivalent to the ETS price over Phase IV. However, this was not quantitatively assessed as it was outside the scope of the project.

[7] Electricity generation is not eligible for free allocation, however indirect CO_2 costs may also increase the risk of carbon leakage so alternative provisions are required. To date, this has taken the form of indirect cost compensation to the most electro intensive sectors for increases in electricity costs as a result of the EU ETS through national aid schemes.

2. AVAILABILITY OF FREE ALLOWANCES EXPECTED IN PHASE IV

2.1. Objective

Given that the free allocation budget will most likely be reduced in order to contribute to an increase in the overall GHG target of 50-55 % by 2030, the objective of this task was to estimate the availability of free allowances over Phase IV taking into account this greater level of ambition.[8]

2.2. Methodology

To estimate the availability of free allowances in Phase IV of the EU ETS, the following two-step approach was implemented:

- *Calculation of preliminary free allocation:* Allocation of allowances to individual installations was estimated based upon the free allocation formula.
- *Calculation of final free allocation:* The preliminary allocation was then checked to make sure it did not exceed the free allocation budget (determined by the ambition of the ETS cap and the mandatory auction share).[9] If the preliminary allocation exceeded the budget for free allocation in a given year, then a Cross Sectoral Correction Factor (CSCF) was applied.

The scope of the estimation of free allocation in Phase IV includes only EEA-30 countries.[10] The following sub-sections provide a detailed description of the calculation of the preliminary free allocation and any subsequent adjustments to estimate the final free allocation for the sectors assessed in this study.

2.2.1. Calculation of preliminary free allocation

The distribution of free allowances to installations is based upon a benchmarking approach. The free allocation of allowances has been estimated for Phase IV based on the following 'bottom up' formula using preliminary NIMs data at the sub-installation level:[11]

Allocation = Benchmark[12] x Historical Activity Level x Carbon Leakage Exposure Factor (CLEF) x Cross-Sectoral Correction Factor (CSCF)

The assumptions applied in order to estimate the preliminary free allocation for Phase IV included:

- *Benchmark values* for the 2021-25 period should be adjusted in respect of each year between 2008 and the middle of the period from 2021 to 2025 with either a minimum annual rate of 0.2 % or a maximum annual rate of 1.6 %, leading to a reduction of between 3 % and 24 % compared to the value applicable in the period from 2013 to 2020 (EU 2018). The European Commission provided this study with estimates of preliminary benchmark values for the 2021-25 period. For the period from 2026 to 2030, those benchmark values should be adjusted in the same way, leading to a reduction between 4 % and 32 % compared to the value applicable in the period from 2013 to 2020 (EU 2018).

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[8] The results contributed to the impact assessment accompanying the Commission's 2030 climate target plan. The assessments were carried out prior to the adoption of the Commission's Communication on the 2030 climate target plan.

[9] The Innovation Fund was not taken into account when deriving the allocation budget. This slightly over-estimates the free allocation budget in Phase IV.

[10] The United Kingdom was not considered within the scope of this study for estimating free allocation in Phase IV.

[11] The allocation process was not finalized at the time of writing.

[12] For product benchmarks that are based also on indirect emissions a ratio to take into account the exchangeability of fuels and electricity was applied to ensure that only direct emissions were given free allocation (refer to Section 8.1.1 in the Annex for the product benchmark values where this applies).

However, as there is no information on future reductions, a simplified approach has been adopted that assumes no reductions in GHG intensity between 2016-17 and 2021-22 and can thus be considered a conservative approach (refer to Table 8-1 in the Annex for an overview of the benchmark values applied).[13]

- *Activity levels* were estimated based upon historic information extrapolated using annual growth rates by NACE 4-digit sector (informed by PRIMES modelling)[14] for the time period 2019-25 and 2026-30.[15] For the year 2019, the annual growth rate for the 2019-25 time period was initially multiplied by the historical average activity rate for 2017-18. In each subsequent year, the activity rate was determined by multiplying the relevant annual growth rate by the activity level of the previous year up until 2030 (refer to Table 8-2 in the Annex for an overview of the activity rates applied).
- *Simplification of free allocation rules* have been applied in the model for Phase IV with an adjustment to allocation based on the production changes above or below 15 % of the historical activity level (HAL) of a sub-installation as a two-year rolling average, which then impacts the subsequent year's allocation.[16]
- *Projected emissions* were estimated based on the conservative assumption that no abatement will occur over Phase IV, therefore the emissions for each NACE 4-digit sector assessed in this study were assumed to change at the same rate as the activity growth rate estimated from the PRIMES modelling.[17] The last year of verified emissions was multiplied by the relevant activity growth rate in order to project emissions forward to 2030.
- *Correction of verified emissions* at sector level were made so that benchmark allocation and emissions were comparable with one another. This was necessary as emissions may be under-estimated when related CO_2 is emitted in other ETS sectors. For example, when heat is purchased from a district heating network or waste gases are transferred to and combusted in other ETS installations, emissions are reported in other sectors. Those emissions were therefore added. However, emissions may also be over-estimated compared to free allocation if emissions from on-site electricity generation are included as electricity generation is not eligible for free allocation. Related emissions were therefore deducted to ensure installations with and without their own electricity production were comparable with one another. The majority of the corrections to verified emissions were within 10 % of the average value from the EU Transaction Log (EUTL) (refer to Section 8.1.3 of the Annex for further details).

2.2.2. Calculation of final free allocation

The preliminary free allocation was then multiplied by the CLEF and the CSCF in order to determine the final allocation for the different sectors. If a sector is deemed to be at risk of carbon leakage in Phase IV, then the sub-installations belonging to the sector will receive allowances equivalent to 100 % of the relevant benchmark for free

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13 The update to the benchmark values for 2021 to 2025 will be determined based upon information submitted for the years 2016 and 2017 while the update to the benchmark values for 2026 to 2030 will be determined based upon information submitted for the years 2021 and 2022 (EU, 2018).

14 The PRIMES model is an EU energy system model which simulates energy consumption and the energy supply system.

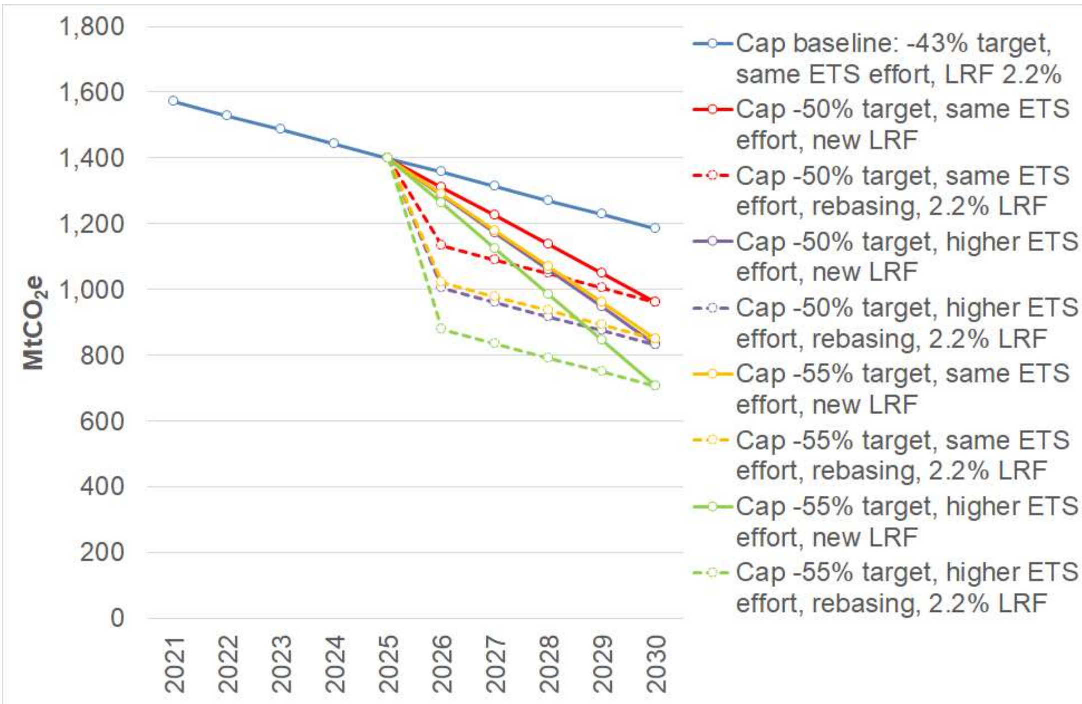
15 This study commenced prior to the Covid-19 crisis and therefore the activity rates of stable but low growth that were assumed for each NACE 4-digit sector did not take the economic shock resulting from the global pandemic into account. Depending upon the longevity of the economic impact of the Covid-19 crisis this could require an update of the study to reflect activity rates that are more representative.

16 The simplified implementation of this rule impacts the preliminary allocation for some installations in the 2021-25 allocation period resulting in an overall increase in preliminary allocation to reflect an increase in production over the time period compared to the HAL in 2014-18. However, there is no impact of this simplified rule on the preliminary allocation in the 2026-30 allocation as the updated HAL in 2019-23 is estimated based on the annual growth rates from PRIMES that do not exceed 1.2 % and therefore do not trigger an adjustment to the preliminary allocation.

17 This implies no further reduction in GHG intensity and thus is likely to over-estimate emissions. The share of direct emissions covered by free allocation is therefore a very conservative calculation. It is very likely that at least some of the abatement potential identified in Section 3 will increase the share of direct emissions that are covered by free allocation in Phase IV for the industrial sectors assessed in this study.

(corresponding to a CLEF of 1). For installations in other sectors, not on the carbon leakage list, the free allocation is gradually reduced from 30 % in 2026 to 0 % by 2030. The CSCF is triggered if the preliminary allocation based on the allocation rules would exceed the budget available for free allocation which depends on the ETS cap scenario. Figure 2-1 shows several scenarios for the ETS cap during Phase IV that were developed by DG CLIMA to take into account different levels of enhanced ambition as well as how the economy wide GHG target could be distributed between ETS and non-ETS sectors. The reduction of the ETS cap in Phase IV could be achieved by either an increase of the Linear Reduction Factor (LRF) or alternatively by re-basing the ETS cap from 2026 onwards.

Figure 2-1 Scenarios for increasing the ambition of the ETS cap in Phase IV



Note: The level of ETS effort refers to the GHG reduction from ETS sectors compared to non-ETS sectors that are currently agreed to achieve the economy wide EU target for 2030. For cap scenarios that assume a higher ETS effort, 5 % more effort is put on ETS sectors resulting in a more ambitious GHG reduction.

Source: Own calculation based upon guidance from the European Commission.

2.3. Key findings

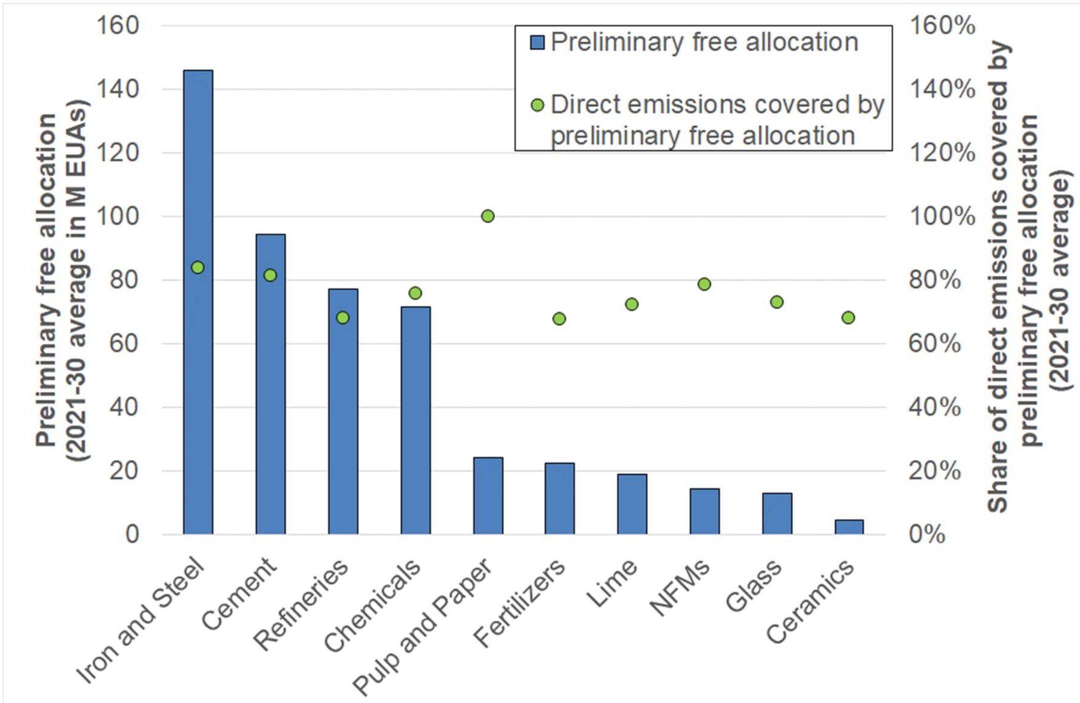
2.3.1. Preliminary allocation

The majority of the sectors assessed in this study are estimated to have between 65 to 85 % of their direct emissions covered by preliminary free allocation during Phase IV. Iron and steel, cement, refineries and chemicals (excluding fertilizers) are on average all within this range between 2021-30 and collectively account for around 70 % of the total preliminary free allocation over Phase IV. The result underlines the importance of the setting of the product benchmark, the values of which for the 2026-30 period are yet to be determined and will depend upon emission developments in the 2019-23 time period.[18] Projected changes in activity levels will also influence the distribution of free allowances across the sectors assessed. The development of

[18] It is important to also note that the product benchmark values assumed for 2021-25 used were provisional as the assessment was completed before the final agreement and publication of these values by the European Commission.

activity rates in light of Covid-19 is now even more uncertain. The preliminary free allocation shown in Figure 2-2 should be considered as a conservative estimation as it does not take into account the potential of each sector to implement abatement options in order to reduce their direct emissions and therefore increase the share of their direct emissions that are covered by free allocation.

Figure 2-2 Estimated preliminary free allocation (2021-30 average)



Source: Own calculation based on data provided by the European Commission (2020a).

2.3.2. Final allocation

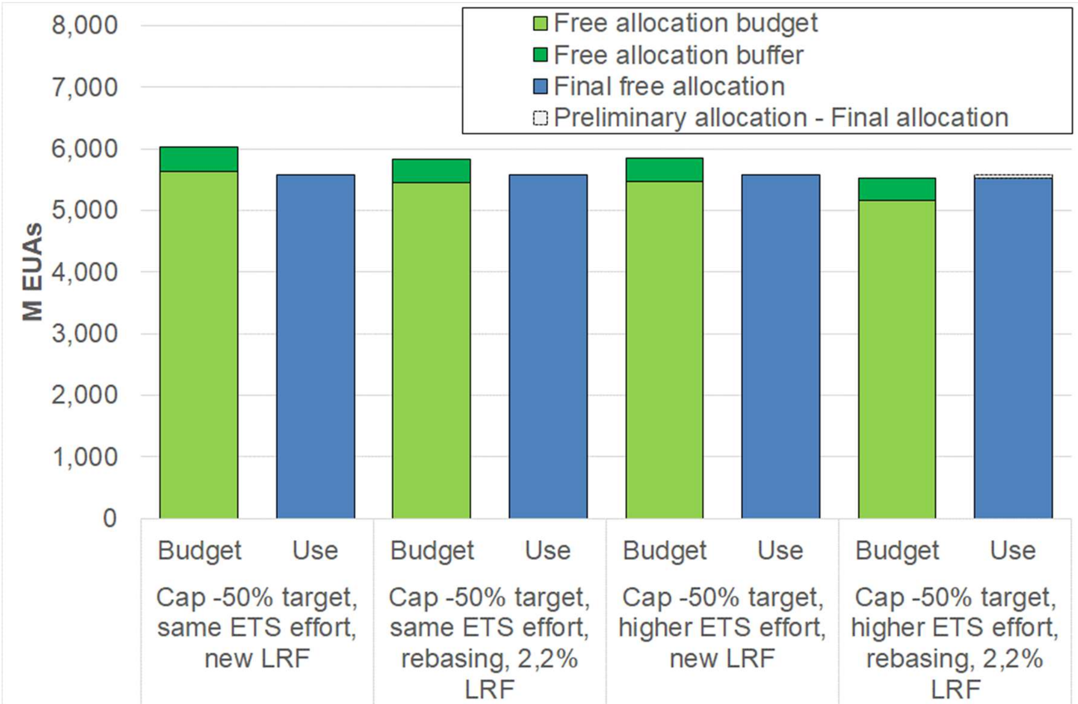
For the ETS cap scenarios that were assessed in this study, the triggering of the CSCF was less dependent on the setting of the overall economy wide GHG target of 50 or 55 % below 1990 levels but more dependent upon how the increased overall ambition was actually translated into a new ETS cap. The level of effort required by the ETS (i.e. compared to the non-ETS sectors covered by the Effort Sharing Regulation (ESR)) and the option selected for implementing the lowering of the ETS cap from 2026 onwards (i.e. rebasing of the cap or adjusting the LRF) were the key variables influencing whether or not the CSCF was necessary for a given scenario.

The rebasing of the ETS cap to contribute to a higher level of ambition (either towards the overall economy wide GHG target of a 50 % or 55 % reduction below 1990 levels) resulted in a triggering of the CSCF in three of the four scenarios that assumed rebasing, but this was only very limited in two of these scenarios. In contrast, the application of a new LRF rather than a rebasing of the cap did not trigger the CSCF in any of the four scenarios that assumed a new LRF, even for different levels of ETS effort[19] towards a 50 % or 55 % economy wide GHG target below 1990 levels (refer to Figure 2-3 and Figure 2-4). This reflects the fact that the use of an increased LRF from 2026 onwards has a more gradual impact than the rebasing of the cap in 2026 and

[19] The different cap values in Figure 2-3 and Figure 2-4 reflects the distribution of reductions between ETS and ESR.

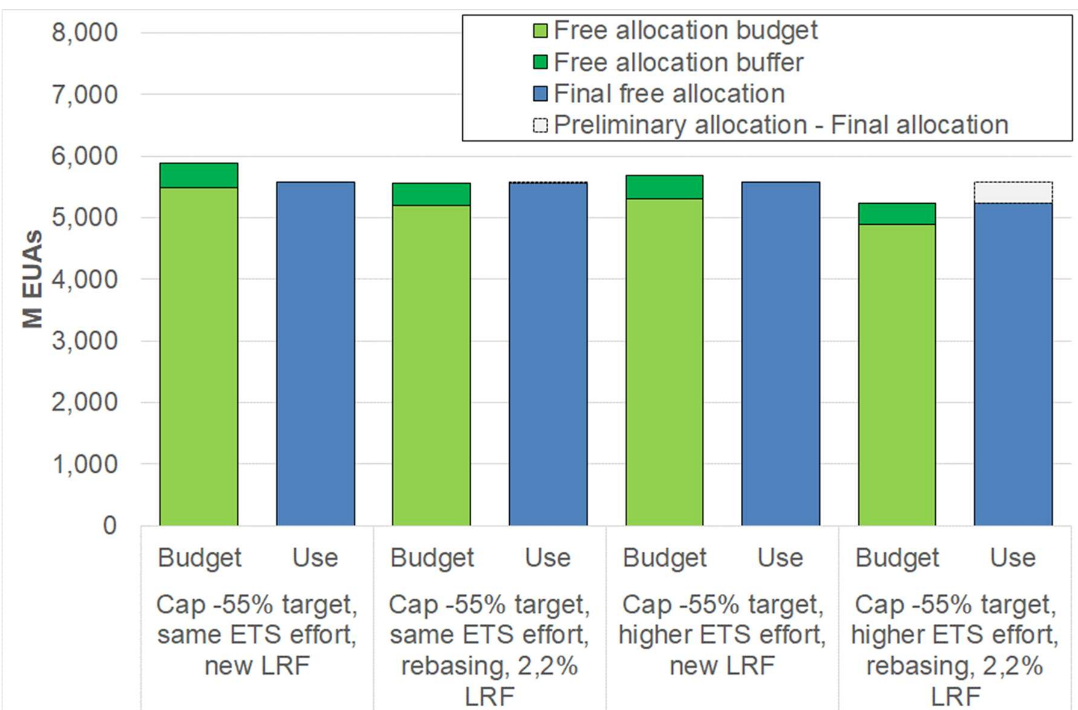
then continuing with an LRF of 2.2 % until 2030. The budget for free allocation plus the buffer was therefore higher for the scenarios where the ETS cap was not rebased.

Figure 2-3 ETS cap scenarios contributing towards a 50 % overall GHG target



Source: Own calculation based on data provided by the European Commission (2020a).

Figure 2-4 ETS cap scenarios contributing towards a 55 % overall GHG target



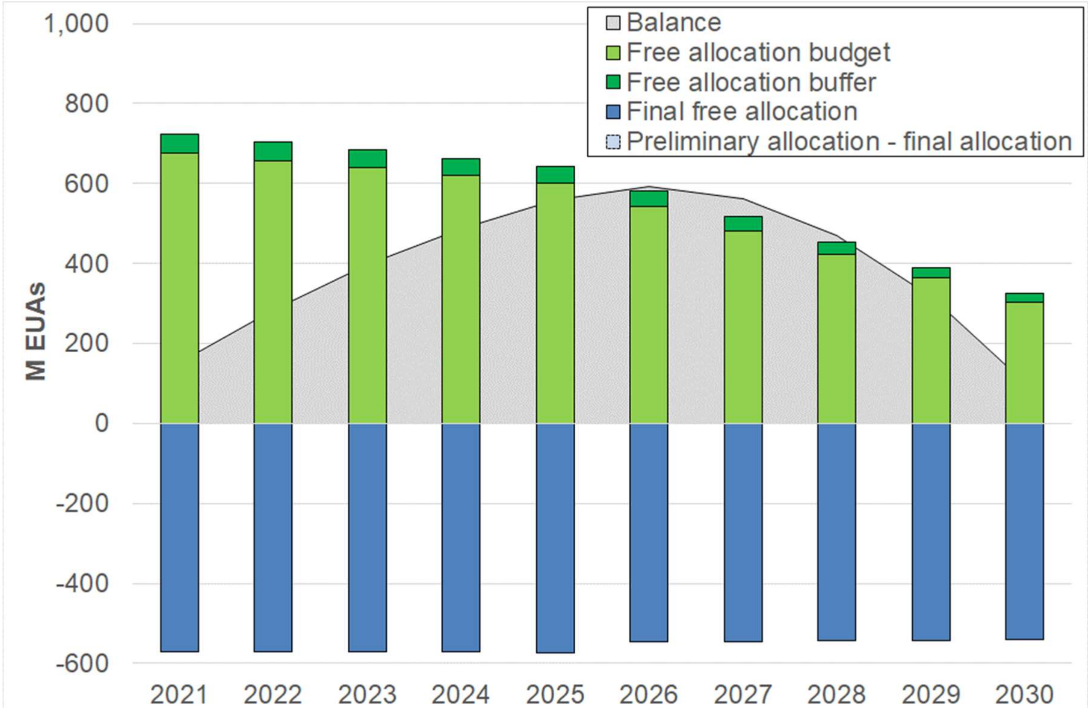
Source: Own calculation based on data provided by the European Commission (2020a).

A key finding of the study is that, due to the application of a buffer[20] over Phase IV to supplement the free allocation budget, the CSCF is not triggered to a significant extent in the majority of the ETS cap scenarios assessed. Figure 2-5 shows that even for an ETS cap scenario whereby the ETS contributes a higher level of effort towards a 55 % overall GHG target by adjusting the LRF from 2026 onwards does not result in the CSCF being triggered as the buffer offsets the deficit in the free allocation budget in the later years of Phase IV. This shows how the adjustment of the LRF from 2026 onwards has a more gradual impact on the free allocation budget compared to the immediate impact of rebasing the ETS cap.

Figure 2-6 shows that the rebasing of the ETS cap in 2026 to contribute towards a 55 % overall GHG target with a higher level of ETS effort leads to the greatest reduction to the free allocation budget and the buffer. The balance between preliminary and final allocation, which had previously increased up until 2025, is projected to quickly deplete in the years 2026, 2027 and 2028 under this scenario so much so that CSCFs of 0.77 and 0.60 need to be applied respectively in the years 2029 and 2030 to ensure that the final allocation does not exceed the free allocation budget. However, it is important to acknowledge that the main advantage of scenarios to rebase the cap is that it would trigger abatement earlier. At the same time, the price signal would also be strengthened.

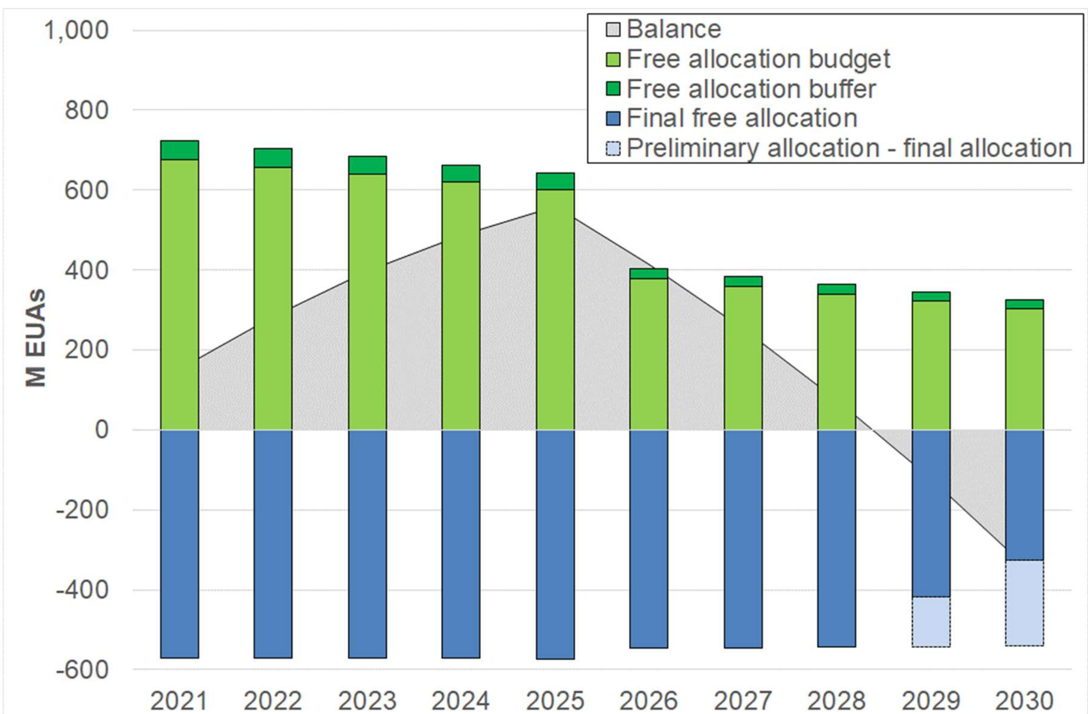
[20] The term buffer in this study refers to the cumulated unused allowances from the non-auctioned ETS share of 43 % of the total cap plus an additional 3 % of the total cap (if necessary to avoid the use of the CSCF).

Figure 2-5 Cap scenario: -55% target, higher ETS effort, new LRF



Source: Own calculation based on data provided by the European Commission (2020a).

Figure 2-6 Cap scenario: -55% target, higher ETS effort, rebasing, 2.2% LRF



Source: Own calculation based on data provided by the European Commission (2020a).

3. Abatement potential identified across the sectors

3.1. Objective

The aim of this task was to estimate the abatement potential in each of the sectors assessed up until 2030. The abatement potential identified should be considered as a first-order estimate based on the best available information from literature.

3.2. Methodology

3.2.1. Estimation of abatement potentials

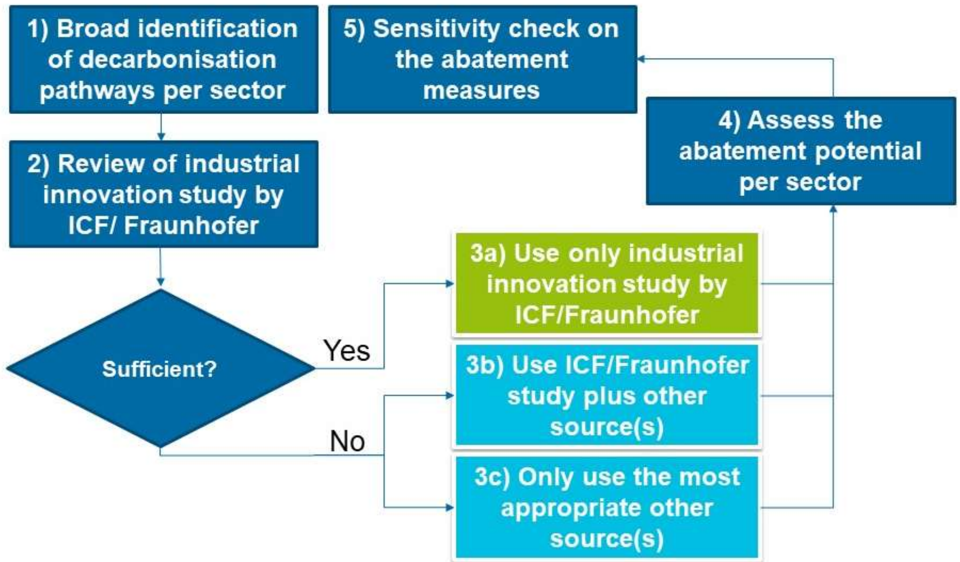
The sectors were approached in a consistent way, by using an existing decarbonisation study from ICF and Fraunhofer ISI (2019). That study was conducted on behalf of the European Commission and explored the possible contribution of individual technologies (per sector) in decarbonising industry and the possible paths that lead to this by 2050. The study used the FORECAST simulation model (developed by Fraunhofer ISI) to model eight alternative scenarios. The results showed that the GHG emissions of industry could be reduced by 80 to 95 % by 2050 compared to 1990. The analysis and scenarios from the ICF and Fraunhofer ISI (2019) study were the main information sources used for the assessment of the abatement potential in each sector. However, other sources were also used when the sector coverage was deemed to be insufficient. If these additional sources or industry roadmaps indicated additional abatement options, these were also considered in the assessment. Table 8-3 in the Annex summarises the sources of data used for the estimation of the abatement potential for each sector.

The FORECAST model from the ICF and Fraunhofer ISI (2019) study acknowledged that available data regarding the required investments for industrial decarbonisation are uncertain, with a broad range of costs estimated by different sources. This is unsurprising as many innovative processes are not yet commercially available in the market, and their future technology deployment pathway might significantly change. Accordingly, it is important to highlight that the assumptions made for the estimations of the abatement costs could vary significantly with energy prices, technology costs and carbon prices. Also, the availability of capital to invest in these abatement options plays an important role in their uptake. The abatement potentials taken from these sources were therefore estimated conservatively, where low uptake rates were chosen for immature/costly technologies. Technologies with a lack of credible data, very high costs or low technology readiness were also left out.

To estimate the abatement potential for each sector, the general approach illustrated in Figure 3-1 was implemented. The preferred approach for each sector was to follow the abatement analysis performed in the ICF and Fraunhofer ISI (2019) study provided that the data contained therein were deemed sufficient. This approach 3.a was applicable to the cement, iron and steel, pulp and paper, non-ferrous metals, ceramics and lime sectors. However, for several of these sectors, the analyses were also complemented with data from other sources to fill gaps. The chemicals (except fertilizers) sector and the fertilizer sector followed approach 3.b by supplementing the research from the ICF and Fraunhofer ISI (2019) study with work from DECHEMA (2017) and FertilizersEurope (2018) respectively to provide further details on abatement options. Due to the lack of sufficient information on the refineries and glass sectors in the ICF and Fraunhofer ISI (2019) study these sectors followed approach 3.c, where the Concawe (2019) study was used for refineries sector, and the DECC

(2015), Glass Alliance Europe (2019), Glass for Europe (2020) studies were used for the glass sector.[21]

Figure 3-1 Decision making process for estimating abatement potentials



Source: Own illustration.

For the sectors following approaches 3.a and 3.b, the abatement measures identified in step 2 were investigated in more detail to estimate the total abatement potential per sector for the time span between 2020 and 2030. The FORECAST model applied a sector specific bottom-up approach to provide a detailed view on the GHG emissions and abatement scenarios for the energy-intensive industrial sectors. The most ambitious scenario in the FORECAST model entitled '4b-Mix95' modelled measures aiming at an economy-wide (not per sector) >95 % GHG emissions reduction by 2050. This scenario was used as the basis for estimating emissions abatement in this study, where this scenario was assumed as being equivalent to the maximum abatement potential for the abatement measures identified (expressed as a percentage reduction below a reference level of emissions in 2030).[22] In step 4, an uptake rate for each abatement measure was then assumed for the time span between 2020 and 2030, based on several factors that included:

- *Projections of the FORECAST model for 2050*,[23] using an anticipated pathway towards the 2050 result as a good indication for 2030 when 2030 results were not explicit;
- *Technology readiness level (TRL)* of the identified abatement measures;
- *Economic feasibility* (cost) of the identified abatement measures.

Several approaches were then used in parallel to estimate the emissions reduction potential by 2030 for each of the abatement options, based on which approach would give the most reliable estimate given the amount of data available. In most cases, the abatement potential was estimated as follows:

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[21] The main sources of data used for estimating the abatement potentials are summarized in Table 8-3 in the Annex.

[22] The independent take-up of each of the abatement measures identified was assumed in this study, where the abatement measures can be implemented independently of each other, and therefore that the GHG emission reductions stack rather than overlap.

[23] The team would like to thank Fraunhofer ISI for kindly agreeing to share some FORECAST model outputs and data to support the work in this task.

1. *Calculation of the maximum potential of an abatement measure in Mt CO_2e:* Multiplying the maximum abatement potential of each abatement measure (expressed as a percentage) by the 2030 reference level for emissions (assuming no abatement);[24]
2. *Calculation of the share of the maximum potential realised in Mt CO_2e*: Multiplying the maximum abatement potential (calculated previously) by the assumed uptake rate (expressed as a percentage) assumed for each abatement measure by 2030.

In some cases, however, the abatement measures only abates emissions in a specific part of the process (i.e. sub-process) and in such cases, the relative abatement potential within that process was multiplied by the estimated share of emissions for the sub-process and then multiplied with the assumed uptake rate of the abatement measure by 2030. It is also worth noting that the application of best available techniques (BATs) was considered as an abatement measure in each sector and was estimated based on FORECAST model data for the year 2030, which estimated emission reductions from applying BATs in a dedicated BAT scenario.[25] Notably, emissions reductions from applying BAT resulted in a major share of the emission reductions in most of the studied sectors (refer to Section 3.3). Similarly, the carbon capture and storage (CCS) potential was based on a dedicated CCS scenario from the ICF and Fraunhofer ISI (2019) study.

Alternative sources were used to estimate the abatement potential for sectors following approach 3.c. In the refinery sector, for example, the ICF and Fraunhofer ISI (2019) study assumed a massive reduction in the production of refinery products by 2050. This is not in line with the aim of this study, which analyses the abatement potential within the refineries sector assuming that the production will remain more or less stable. Accordingly, the analysis used data from a study by Concawe (2019) that analysed a set of different decarbonisation pathways for the entire value chain of liquid fuels until 2050 to estimate abatement potentials. For the glass sector, the abatement measures applied in the 4b-Mix95 scenario from the ICF and Fraunhofer ISI (2019) study were also considered to be too limited and therefore data from other sources were used instead.

In the last step, a sensitivity check was applied to the uptake rates of the abatement measures, to test the effect on increasing or decreasing the abatement potentials per sector. For example, in the sensitivity check an increase in the uptake of CCS measures was tested. If this was set to 2 % in the main analysis, then an uptake rate of 1 % and 5 % was also considered. The levels for the sensitivity analysis were set individually per measure. The sensitivity analysis showed that the results were quite robust to these types of changes in the uptake assumptions and that the overall abatement potential estimates were in the right order of magnitude when compared to available sector's roadmaps.

3.2.2. Limitations and uncertainties of the abatement potential results

It is important to highlight that applying approach 3.a, 3.b or 3.c. produces different sets of results, due to the differences in the identified mitigation scenarios and the underlying assumptions that include not only uptake rates of mitigation potentials, but

[24] Since the projected emissions in 2030 from the ICF and Fraunhofer ISI (2019) study were based on the FORECAST model reference emissions in 2030, it was necessary to correct the emissions reduction potential identified. This correction ensured consistency with the emission projections that were previously applied in Section 2 in order to estimate the extent to which free allowances will cover the direct emissions of energy intensive industrial sectors in Phase IV of the EU ETS.

[25] In order to address the reductions in production (demand) per sector assumed by the FORECAST model for some sectors in the ICF and Fraunhofer ISI (2019) study, the BAT calculations were corrected to exclude the effect of demand reduction from the emissions reductions estimations. This correction was done for the abatement deriving from a reduction in the production that was assumed in the ICF and Fraunhofer ISI (2019) study, but not in the production trajectory assumed in this study.

also energy costs, technology costs and carbon prices. Therefore, there are complexities in comparing the abatement potentials across sectors and they are not well suited for aggregation towards a total abatement potential for the energy-intensive sectors. There are also substantial uncertainties on uptake rates and thus abatement potentials of several abatement options due to:

- Uncertainty on the pace of technology development;
- Uncertainty around the abatement cost;
- Uncertainty on the carbon price by year 2030.

3.3. Key findings

Figure 3-2 presents a first order estimate of the maximum abatement potential for each industrial sector by 2030, taking into account key assumptions regarding economic feasibility, carbon prices, technology readiness and actual uptake of the abatement measures by 2030. Although, a comparison of the relative abatement potential of each sector was constrained by the limitations in the methodology (see Section 3.2.2), the abatement options identified for each industrial sector were aggregated into the following categories below in order to facilitate a more qualitative comparison across sectors.

- *Best Available Techniques (BATs) and process efficiency:* This abatement category plays an important role for most sectors up until 2030.[26] This reflects the fact that these measures are associated with a lower abatement cost and higher technology readiness level compared to more innovative technologies. The abatement potential from BATs and process efficiency accounted for over two thirds of the total abatement potential for the iron and steel and non-ferrous metals sectors. In the iron and steel sector, the high contribution of BATs to total abatement in 2030 was influenced considerably by the assumed potential for incremental process improvements as well as an expansion of secondary steel production using electric arc furnaces in the 4b-Mix95 scenario from the ICF and Fraunhofer ISI (2019) study.[27] In the non-ferrous metals sector, the high contribution of BATs to total abatement in 2030 reflects the more limited potential for a reduction in direct emissions from more innovative technologies.
- *Switching to other energy carriers (for energy or feedstock):* This abatement category accounts for over 20 % of the total abatement potential in 2030 for the non-ferrous metals, ceramics, chemicals (excluding fertilizers) and refinery sectors (and even more if the switch to renewable hydrogen would have been included in this category). This abatement measure mainly involves the reduction of petroleum-based fuels for these sectors with alternative fuels such as biomass. For chemicals (excluding fertilizers), however, the measure accounting for the majority of the abatement potential in this category was the production of bio-ethylene based on a biomass feedstock.
- *Process innovation abatement measures:*[28] The majority of the abatement potential identified in this study for the cement sector (i.e. around 90 %) relies upon a reduction in the clinker to cement ratio and the increasing use of forms of low carbon cement. This abatement category also contributes around 40 % of the total abatement potential identified in 2030 in this study for both the pulp and paper and glass sectors. Examples of abatement options include the use of new drying techniques in the pulp and paper sector and the adoption of

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[26] An overview of the BAT & process efficiency options considered for each sector is provided in Table 8-4 of the Annex.

[27] Between 2015 and 2030, the EAF share in EU steel production is estimated to grow from 40 % in 2015 to roughly 50 % in 2030 (in 2018 the EAF share was 41.5 %). The feasibility of this growth rate will also depend on the quantity and quality of available steel scrap and innovations in the EAF process that can ensure sufficient steel product quality.

[28] In general, abatement measures which fall under this category are characterised by a relatively low TRL level (TRL ≤7).

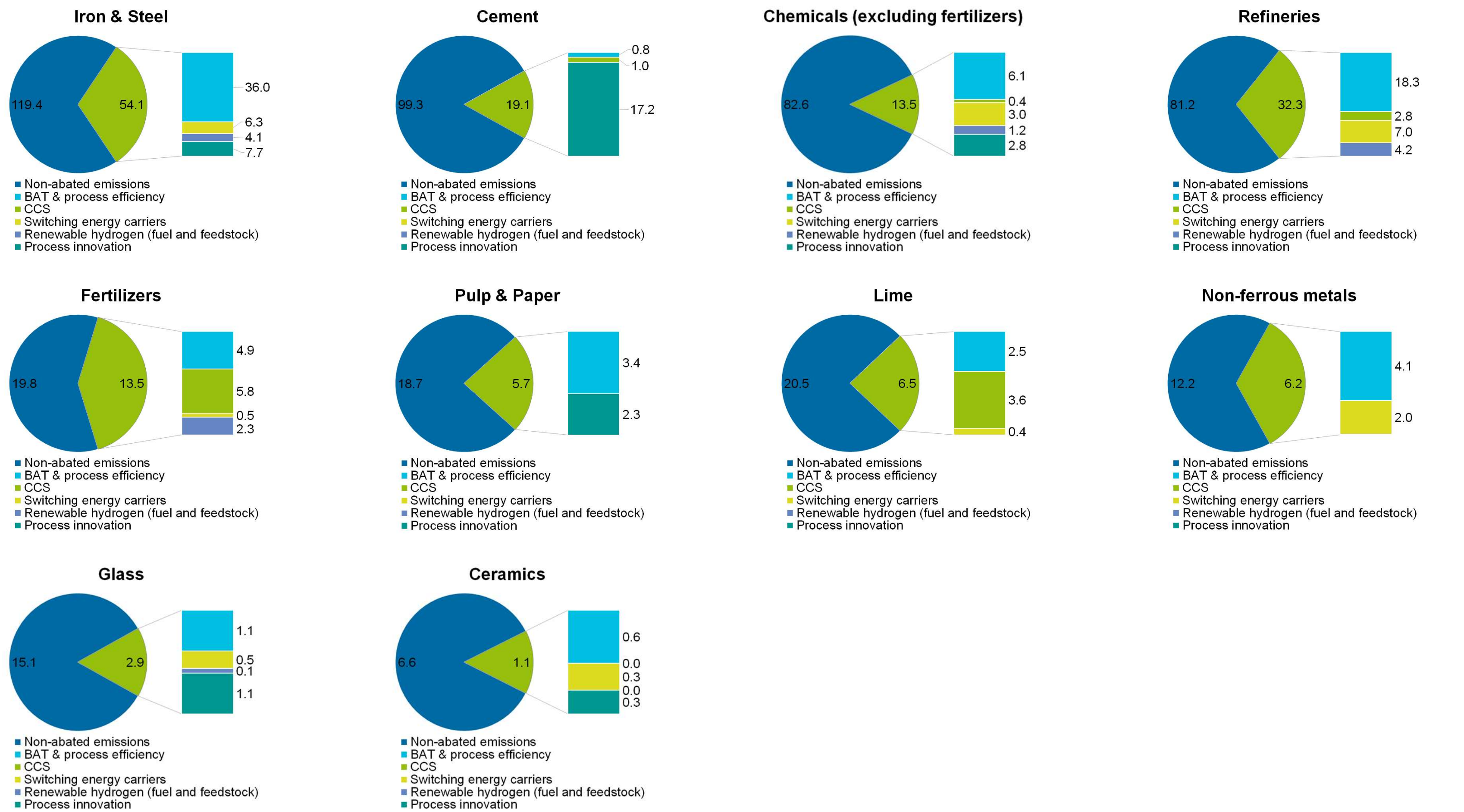
batch pellitization in the glass sector. Process innovation abatement measures account for a smaller share of the abatement potential in the other sectors assessed. Examples of such abatement potential includes the adoption of electrolysis DRI in steelmaking that is associated with a low technology readiness level as well as near net shape casting.

- *Switch to renewable hydrogen:* In sectors such as fertilizers and refineries, hydrogen is already used as part of the standard production process. A switch implies substitution of fossil produced H_2 by renewable electricity based H_2, a more affordable and more straightforward change than in other industries. This is reflected by the fact that a switch to renewable hydrogen accounts for 17 % and 13 % of the total abatement potential by 2030 identified in this study for the fertilizer and refinery sectors, respectively. However, even though these abatement potentials are technically achievable by 2030, significant policy support will be needed for these solutions to reach sufficient scale in the coming decade. For sectors other than refineries and fertilizers, the use of renewable hydrogen implies a switch to completely different production processes, with added complexities and costs. The abatement potential relating to hydrogen-based iron-making processes is relatively low, as the uptake is expected to still be very limited in 2030, due to high abatement costs, low technological readiness or a combination of the two.
- *Carbon capture and storage (CCS):* CCS deployment is limited in most sectors up until 2030. An exception is CCS at steam methane reforming (SMR) installations, which has a more cost-efficient potential in the fertilizer and refinery sectors. Furthermore, post-combustion CCS in lime production is relatively cost-efficient as well. In the 4b-Mix95 scenario, there is no deployment of CCS in the iron and steel sector and only limited deployment of CCS in the chemicals (excluding fertilizers) and cement sectors, as more radical abatement options are more attractive given the long-term ETS price developments.[29] However, if the implementation of other techniques proves to be very challenging, the implementation of CCS can still be a viable option in these sectors if barriers to implementation can also be overcome.

In conclusion, this first order estimate of the abatement potential up until 2030 shows that many opportunities are available to reduce the emissions of industry that would help to significantly reduce the expected shortage of free allowances in Phase IV of the EU ETS (refer to Section 2.3.1). The implementation of all the abatement measures by 2030 seems to be challenging, since several of these measures require long-term investments and it is unlikely that the maximum abatement potential estimated in Figure 3-2 could be fully realised up until 2030 without further incentives (e.g. via a stronger ETS price signal or further innovation funding). It is however also possible that technical breakthroughs could reduce costs in the coming years and make some of the abatement measures more attractive than currently assumed. The results presented in this study should therefore only be regarded as an indication of the abatement potential for each sector. Indeed, it is evident from this study that further engagement with industry on how best to estimate abatement potential and cost will be essential in the coming years to ensure the right level support for decarbonisation.

[29] The 4b-Mix95 scenario, which was used to quantify the 'maximum' abatement potential in this study, assumed an ETS price of 100 EUR/ tCO_2 in 2030 as a starting point. As a consequence, the uptake of more expensive GHG abatement options was relatively high in this scenario, as the high CO_2 price incentivises investments in mitigation technologies. This price assumption differs from (is higher than) the CO_2 price assumptions used in later modelling for the EC for 2030.

Figure 3-2 Abatement potential estimated for each sector by 2030



Source: ICF and Fraunhofer ISI (2019) study with additional sources (refer to Annex) and expert judgements from the project team and own calculations.

4. VULNERABILITY TO CARBON LEAKAGE BASED ON SECTOR CHARACTERISTICS

4.1. Objective

The preliminary results of the study so far suggest that most sectors will likely be short of allowances in Phase IV but that this could, at least in part, be offset by emission reductions identified in the literature. However, the extent to which these sectors will be vulnerable to carbon leakage will also be determined by their ability to either absorb or pass on costs related to emission reductions as well as direct and indirect carbon costs. It was, however, beyond the scope of this study to assess cost pass-through rates. Instead, the characteristics of a sector that are likely to influence the impact of any additional carbon cost on their international competitiveness were assessed in this section. Key indicators are proposed as a starting point for grouping sectors in the future according to their vulnerability to carbon leakage.

4.2. Methodology

In order to assess the vulnerability of industrial sectors to carbon leakage, the following indicators have been developed based upon consistent datasets across sectors:

- *Carbon leakage indicator values* had previously been calculated for industrial sectors at the NACE 4-digit level in the Carbon Leakage List exercise for 2021-30 (European Commission 2018) based upon their trade intensity and emission intensity. The trade intensity provides an indication of a sector's exposure to international competition while the emission intensity provides an indication of a sector's direct carbon cost. If a sector is exposed to international competition and is faced with relatively high direct carbon costs compared to other sectors, then there is the potential for that sector to be vulnerable to carbon leakage.
- *Shares of direct emissions in total emissions* were calculated based upon information from the NIMs dataset for the 2014-18 time period (European Commission 2020a) to provide an indication of the extent to which free allocation of allowances could provide carbon leakage protection given that free allocation will not fully support sectors with a high share of indirect emissions. If a sector has a high share of direct emissions in total emissions, then free allocation would likely provide more carbon leakage protection compared to a sector with a high share of indirect emissions (depending upon previous carbon leakage indicator values).
- *Imports relative to domestic market* were calculated based upon PRODCOM value data for all sectors (EUROSTAT 2020b, 2020a) with the exception of refineries (due to a lack of data) and provide an indication of potential carbon leakage for a sector if imports increase rapidly relative to the domestic market (i.e. imports + sold production) over time. However, the extent to which such a trend represents carbon leakage will also depend on whether the importing country has comparable levels of carbon pricing. It is important to acknowledge that other factors such as trade tariffs, state subsidies and market fundamentals may also influence changes in trade patterns.
- *Exports relative to production* were calculated based upon PRODCOM value data for all of the sectors (EUROSTAT 2020b, 2020a) with the exception of refineries (due to a lack of data) and provide an indication of potential carbon leakage for a sector if exports decline rapidly relative to levels of sold production over time. However, the extent to which such a trend represents carbon leakage will also depend on the circumstances in the export market, as for example government policies could limit imports in order to promote domestic production.

Based upon these indicators, a framework for grouping sectors according to their carbon leakage vulnerability was proposed in this study in order to inform policy makers on how best to target free allocation in Phase IV and whether or not alternative measures beyond free allocation should be considered to protect against carbon leakage in certain sectors, while avoiding windfall profits.

4.3. Key findings

An overview of the key indicators considered in this study to assess the vulnerability of a sector to carbon leakage is provided in Table 4-1. Based upon these indicators, the following four groups have been proposed as a starting point for a possible framework to categorise sectors according to their vulnerability to carbon leakage:

- *Low emission intensity, mainly direct emissions:* Sectors with relatively low emission intensities and a high share of direct emissions in their total emissions may be less vulnerable to carbon leakage compared to other sectors due to lower direct carbon costs.
- *Low emission intensity, mainly indirect emissions:* Indirect emissions are reflected in the carbon leakage status of the sectors, but not addressed by free allocation. Table 4-1 shows that the share of direct emissions in total emissions is relatively low for the pulp and paper and non-ferrous metals sectors relative to the other sectors assessed. Given that the indirect emissions associated with these sectors are not addressed by free allocation and that the decarbonisation of the power sector is still an on-going process, a relatively high share of indirect emissions points in the direction of a higher carbon leakage risk, compared to the first category.
- *High emission intensity, low trade intensity, but exposure to international competition depending upon transportation cost:* The EU's list of sectors deemed at risk of carbon leakage does not differentiate between different regions and thus does not take into account the proximity to transportation hubs. Table 4-1 shows that the trade intensity of cement and lime are relatively low compared to other sectors. However, key trading partners are mainly located at the EU border so data on trade flows at regional level and on transportation costs would be needed to better determine the risk of potential carbon leakage.
- *Medium trade intensity, medium emission intensity:* Sectors that are associated with a higher value to weight ratio for their emission intensive products means that transportation costs are likely to be less of a barrier for preventing the risk of carbon leakage. Several sectors such as iron and steel, refineries, fertilizers and chemicals (excluding fertilizers) are associated with relatively high carbon leakage indicator values. Sectors in this final grouping are potentially more vulnerable to carbon leakage as they are associated with a relatively high import share compared to their domestic market and import significant trade value from countries without comparable forms of carbon pricing. Sectors in this grouping may require more targeted support from the free allocation that remains available in Phase IV of the EU ETS if they are unable to absorb or pass on their carbon costs.

The classification of a sector within a particular grouping is, however, beyond the scope of this project and the examples provided above should only be considered as illustrative in order to facilitate further discussions on how best to target free allocation in Phase IV and where alternative support provisions may be more effective. Further research will be required to determine the exact thresholds to set for the quantitative metrics identified in this framework as well as the level of disaggregation (i.e. NACE 4-digit level or beyond). Furthermore, additional indicators such as the relative profitability of a sector, changes in market share and alternative measures of emission intensity could all be considered in the future if there is a consensus amongst industry on how best to derive representative values using publicly available datasets.

It will be important to monitor the development of all indicators considered in this framework over time, especially if EUA prices increase, in order to assess how the vulnerability of a sector to carbon leakage may be subject to change.

Table 4-1 Overview of key indicators to assess the vulnerability of a sector to carbon leakage

	NACE	Trade intensity	Emission intensity	Carbon leakage indicator	Share of direct emissions in total emissions[30]	Imports relative to domestic market (average)	Imports relative to domestic market (change)	Exports relative to production (average)	Exports relative to production (change)
Iron & Steel	24.10	25.7%	8.3	2.1	85%	14%	5%	13%	-2%
Refineries	19.20	25.8%	12.5	3.2	90%	*	*	*	*
Chemicals (excluding fertilizers)	20.11	6.0%	16.8	1.0	84%	19%	4%	27%	4%
	20.12	48.5%	1.1	0.5					
	20.13	54.0%	3.0	1.6					
	20.14	49.0%	2.2	1.0					
	20.16	36.0%	0.9	0.3					
	20.17	55.1%	1.1	0.6					
Cement	23.51	10.1%	24.2	2.5	99%	1%	0%	7%	-3%
Pulp & Paper	17.11	48.1%	2.1	1.0	47%	9%	1%	23%	1%
	17.12	27.8%	3.0	0.8					
Fertilizers	20.15	31.8%	7.6	2.4	94%	22%	3%	15%	2%
Non-Ferrous Metals	24.42	35.2%	4.6	1.6	30%	22%	3%	17%	-1%
	24.43	30.6%	3.4	1.0					
	24.44	35.1%	1.2	0.4					
	24.45	83.5%	0.3	0.3					
Lime	23.52	4.9%	20.8	1.0	99%	1%	0%	3%	0%
Glass	23.11	23.7%	6.1	1.5	84%	11%	4%	15%	0%
	23.12	20.6%	0.3	0.1					
	23.13	24.7%	2.6	0.6					
	23.14	28.4%	1.5	0.4					
	23.19	48.5%	0.5	0.2					
Ceramics	23.31	41.1%	2.6	1.0	90%	4%	0%	35%	-2%

Note: Indicator values taken directly from the carbon leakage list exercise for Phase IV are provided at the NACE 4-digit, while the remaining indicator values are calculated at a more aggregated level to match the sector grouping of NACE codes that are used throughout the study. Import and export indicators refer to EU-27 trade with non-EU ETS countries for 2013-18 averages and changes between 2013 and 2018. * No information available for the refineries sector on production from PRODCOM.

Source: European Commission (2018), European Commission (2020a), EUROSTAT (2020b), EUROSTAT (2020a).

[30] The scope of the estimation of the share of direct emissions in total emissions includes only EEA-30 countries. Share of direct emissions in total emissions refers to the average 2014-18 data based on the NIMs dataset. Data on electricity consumption in the NIMs dataset is, however, less reliable as it is not mandatory for installations that only import electricity from the grid to provide an electricity balance. Gap filling was therefore necessary in order to estimate indirect emissions in the aluminium sector. For installations producing primary aluminium without information of electricity consumption in the NIMs it was assumed that the benchmark electricity consumption from the indirect state aid guidelines represent the electricity consumption.

5. ADDITIONAL OPTIONS

This section outlines alternative and complementary policy options to free allocation as it has been implemented in Phase III of the EU ETS and currently set for Phase IV to address carbon leakage and support continued decarbonisation. What follows is an analysis highlighting key design choices and considerations, drawing on existing practices across the globe, the latest and most relevant academic literature, and previous EU impact assessments.

5.1. Tiered approaches to leakage risk assessment and levels of free allocation

As the volume of allowances available to be allocated for free becomes scarcer, it is essential that leakage risk assessment makes nuanced distinctions between sectors based on vulnerability, hence reducing distortions and preserving the budget for those facing relatively higher risk (Acworth et al. 2020). One option to achieve this is setting risk tiers based on different thresholds of emissions and trade intensity and assigning different levels of allocation to each tier. Such a tiered approach has been discussed for the EU ETS and has been adopted by other jurisdictions, including California, Québec, and New Zealand. A tiered approach to allocation would likely avoid triggering the CSCF under the most ambitious 55 % reduction scenario forecasted in this study and has been recommended by the European Court of Auditors (2020). As the sectors in this study generally rank among the most vulnerable of all EU industrial emitters in terms of carbon leakage indicators, a tiered approach would likely prioritise their allowance needs relative to other industrial emitters as free allocation budgets decline, which could help minimise leakage risks in the aggregate if free allocation is maintained as a primary instrument against leakage.

In California and Québec, linked markets with numerous similarities in their regulatory approaches, emissions intensity and trade exposure are divided into tiers with different thresholds. Different combinations of emissions intensity and trade exposure result in an overall classification of low, medium, or high risk. In allocation, an entity's production levels and the benchmark are multiplied by an assistance factor that is assigned to each overall risk classification. In Québec assistance factors of 90 %, 95 %, and 100 % will be applied to the leakage risk categories low, medium, and high respectively from 2021-2023, with possible amendments after 2023. California originally envisioned a steady decline of assistance factors for sectors at low and medium risk starting in 2015 but delayed and then rescinded this plan because of ongoing leakage concerns, meaning all sectors continue to receive 100 % allocation at their respective product benchmark.[31] However, the formula for free allocation includes an annual cap decline factor to ensure free allocation aligns with the cap trajectory. These cap decline factors have been set in regulations through 2031. Industrial activities with a high leakage-risk classification and other measures of leakage vulnerability[32] are assigned a lower cap-decline factor such that in 2031 free allocation will reach about 75 % of 2013 levels (California Air Resources Board 2018). All other activities will reach about half of their 2013 free allocation in 2031.

The impact assessment for Phase IV of the EU ETS also considered tiered allocation through "carbon leakage groups". Two options created four carbon leakage groups based on either different combinations of emissions and trade intensity (Option 3, "Limited Changes") or a combined indicator based on the product of emissions and trade intensity (Option 4, "Targeted"). In both cases, free allocation was proposed to be 100 %, 80 %, 60 %, and 30 % of the benchmark in the "very high", "high", "medium", and "low" groups, respectively (European Commission 2015). Thresholds

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31 The latest product benchmarks and industrial activities eligible for free allocation can be found in California's 2018 cap-and-trade regulation (California Air Resources Board 2018).

32 Activities subject to a slower cap-decline factor also have at least 50 % of their total emissions stemming from process emissions as opposed to indirect emissions and a high emissions-intensity classification overall.

for the “very high” category were set such that only the most exposed sectors qualified to reduce the risk of triggering the CSCF. In both cases, the expectation was that allocation would be better adapted to the estimated risk of carbon leakage and the related ability to pass through costs compared to a binary approach.

According to the results of the impact assessment, tiered categories of carbon leakage risk would result in more targeted free allocation. As the CSCF was not anticipated to be triggered, sectors classified as being at very high risk would receive 100 % of allowances for free at the benchmark level, an increase compared to Phase III, where in 2020 the CSCF reduces free allocation by more than 20 %. Sectors deemed to be at high risk of carbon leakage would receive 80 % of their allowances for free, which would result in a similar allocation as under Phase III, given the adjustments made through the CSCF. Sectors rated as medium risk would receive lower free allocation shares compared to Phase III.

If tiered allocation were considered as part of EU ETS revisions under a higher 2030 target, the key considerations would be the thresholds for determining the tiers, the leakage indicators for assigning sectors to different tiers, and the assistance factor for each tier. These decisions would have implications for the remaining budget of free allocation and potential allowance shortfalls for sectors vulnerable to carbon leakage. This study’s analysis of allocation pathways would provide a starting point for determining the impacts of thresholds and assistance factors in a tier-based approach. Using the same thresholds from Option 4 of the 2015 impact assessment (“Targeted” approach), which uses a combined emissions and trade intensity indicator as in Phase IV, but updating the leakage risk indicators to those determined for Phase IV would result in different classifications of some sectors in this study relative to the impact assessment (see Table 8-5 in the Annex). Only refineries would receive a “very high” classification, though most other sectors would have at least one product in the second-highest tier of “high” vulnerability.

5.2. Consumption charges paired with free allocation

Consumption charges paired with free allocation would present an option to maintain leakage protections for vulnerable sectors while incentivising greater demand-side abatement to 2030. Free allocation to industrial producers would provide leakage protection, while consumption charges would pass on carbon costs downstream. Detailed policy proposals in the EU context have focused on the most emission-intensive sectors in this study, including iron and steel, cement, non-ferrous metals (aluminium), chemicals, and paper and pulp (Neuhoff et al. 2016; Ismer et al. 2016). However, further analysis would be required to determine the impact of consumption charges, with particular attention to mitigation potential among consumers of the covered goods further down the industrial value chain, downstream costs, and substitution effects.

Charges would be levied on the covered products at the point of intermediate or final consumption, both for those produced within the EU and imported goods. This charge could be based on the weight of the material multiplied by a product-specific reference level and the price of an EUA, which could be updated on a regular or semi-regular basis to reduce administrative burdens (Neuhoff et al. 2016). By levying a charge on emissions-intensive basic materials, carbon costs would be passed down the value chain, including to more complex products that contain materials covered by the consumption charge. As a consequence, the charge would provide incentives for reducing the consumption of carbon-intensive materials, for their recycling and for their substitution. However, contrary to the ETS, the charge would not provide incentives for reducing the emission intensity in the production of the concerned basic materials, as uniform reference values for the emission intensity would be used.

EU producers would be held liable for the consumption charges, which they could pay themselves or pass on to intermediate consumers in the form of higher prices. Duty-suspension arrangements for EU firms could provide a means of forgoing consumption charges if their goods are intended for export, in keeping with the destination principle of value-added taxes.

Liabilities upon import to the EU could be incorporated into existing customs-duty procedures and would be equivalent to charges on EU-produced goods. To prevent trading partners from avoiding charges by shifting to exports of intermediate and final goods, the scope of consumption charges could be extended further along the value chain for imported products that contain materials covered by the consumption charges. Estimates show that extending charges on imports to approximately 1,000 product categories of the Harmonized Commodity Description and Coding System would capture about 85 % of emissions from carbon-intensive industrial materials (Pauliuk et al. 2016). However, this more expansive approach would significantly increase administrative demands and potentially data requirements, as it may require setting default values of material content.

EU sectors subject to consumption charges would continue to receive allowances for free to provide leakage protections, as an equivalent charge on like imported goods would not itself provide leakage protection. In the absence of free allocation to producers, consumers would likely face greater carbon costs passed on by producers in addition to the consumption charge.

Choosing a single, uniform product-specific reference level that applies to EU-produced and imported goods alike would help ensure that the charges are not considered discriminatory by the WTO. Using the same value for free allocation to producers and for determining the consumption charge would ensure the charges capture the level of pricing that is otherwise muted upstream through free allocation, which is the central aim of consumption charges on goods from leakage-vulnerable industries.

Consumption charges paired with free allocation would, however, present challenges. First, they place continued reliance on free allocation to maintain leakage protections (Acworth et al. 2020), as the consumption charges do not provide any carbon leakage protection. This calls into question the long-term sustainability of the approach, especially under a more ambitious 2030 reduction target. This challenge may require adjustments to the distribution of free allocation to ensure sectors subject to consumption charges are fully protected. A tiered approach to free allocation could be one way to address this challenge by continuing to grant sectors covered by consumption charges higher or full levels of free allocation at the benchmark level while setting lower free allocations for other sectors that are less vulnerable to carbon leakage. However, a tiered approach that resulted in allowance shortfalls for sectors subject to consumption charges could lead to greater downstream impacts from higher cost pass-through combined with the consumption charges.

Secondly, consumption charges are not aimed at levelling differences in carbon costs at the border and are closer in design to value-added taxes. Therefore, by design, consumption charges would not address differences in carbon pricing on production, evolve with the changing pricing landscape globally, or incentivise abatement among trading partners. EU trading partners who do phase down free allocation would expose their industries to greater carbon costs as well as the consumption charges upon export to the EU. As the charge is exempted for EU goods bound for export under duty-suspension arrangements, it is assumed that any jurisdiction that similarly applies consumption charges is similarly relieving exports of the liability.

Additionally, the potential for trade distortions may require the extension of consumption charges further downstream, which entails administrative and legal complications as goods move beyond basic materials., Furthermore, if the same charge is applied regardless of actual emissions intensity, the system would not address barriers of market entry for innovative low-carbon producers. Lastly, consumption charges would require a dedicated administrative infrastructure triggering potentially significant costs to companies and public authorities.

5.3. Innovation support

The market of low-carbon technologies for emissions-intensive industries remains under developed globally relative to renewable energy, at least partly because of weaker efforts to support their development and deployment (Åhman et al. 2017). The EU ETS alone is not equipped to develop new and breakthrough technologies needed for deep industrial decarbonisation, but rather helps advance more incremental improvements from competing technologies that are on closer footing (Duwe and Ostwald 2018). Therefore, support for both the development and deployment of low-carbon technologies for the sectors in this study is an important complementary policy to achieve abatement potential and thereby reduce vulnerability to carbon leakage. However, it is not suggested as a standalone policy for addressing leakage risk or a direct substitute for free allocation in the absence of other measures to reduce leakage vulnerability. Consumption charges would provide an additional stream of revenue for this innovation support.

The EU has an established architecture spanning the different phases of technological innovation. Horizon 2020/Horizon Europe targets the earliest phases, including basic research and proof of concept in laboratory settings. Starting with Phase IV of the EU ETS, the Innovation Fund will support pilot demonstrations for low-carbon technologies and processes in industrial sectors that are ready to be tested in real environments. Successfully demonstrated projects will then receive support from InvestEU and the Connecting Europe Facility for wider deployment of new technologies and processes.

The Innovation Fund could therefore serve as a mechanism to support the development of low-carbon industrial technologies, targeting technologies identified in the abatement potential analysis of this study, focusing on those with high mitigation potential, high costs, and, where possible, cross-sectoral application. In particular, process innovations could be well-suited to the Innovation Fund, given generally lower technology readiness levels.

InvestEU envisions supporting successful projects from the Innovation Fund, e.g. by de-risking investments as they scale up. One instrument that could be used for de-risking commercialisation of low-carbon technologies through InvestEU or other channels of funding are project-based carbon contracts for differences (CCfDs). Bridging the gap between successful demonstration and commercial application, known as the "valley of death", can be especially challenging for low-carbon industrial technologies owing to factors such as high additional operating costs over long periods of time and uncertain allowance price trajectories (Helm and Hepburn 2005). Industries vulnerable to carbon leakage also face constraints in reflecting the costs of technology or production-process upgrades in their prices.

Building on feed-in-premiums/tariffs used for the electricity sector, CCfDs ensure investors long-term, stable financing for emissions reductions below a certain benchmark e.g. the best available technology. CCfDs set a "reference price" linked to carbon costs the investor faces and a guaranteed "strike price" for the duration of the contract (Richstein 2017). In the EU context, this reference price would likely be the current allowance price. Under a CCfD, a public entity would pay the investor the difference between the strike price and the current EUA price using a formula that also takes into consideration the investor's annual production and the promised emissions reductions below the benchmark (Neuhoff et al. 2019; Sartor and Bataille 2019). The public entity could require investors to return at least a share of profits during periods when the reference price exceeds the strike price.

Numerous aspects of administration, policy design, and legal implications would need to be considered to implement CCfDs. These include conformance with EU state aid laws, the criteria for a competitive bidding process, the methodology for determining strike prices, and whether additional funding through grants in the early years of a contract is justified (Sartor and Bataille 2019; Richstein 2017). There is a strong case to make that CCfDs would be compatible with EU state aid laws given their environmental rationale, a competitive bidding process, the net-benefit of addressing industrial decarbonisation relative to potential market distortions, and their intended focus on early commercialisation of recently piloted technologies (Sartor and Bataille 2019).

6. Conclusion

Given the announcement of the European Green Deal in December 2019, the level of ambition in the EU ETS will be enhanced during Phase IV and this will further limit the ETS cap and the availability of free allowances. As a consequence, the risk of carbon leakage may be greater if less of the sector's direct emissions are covered by free allocation than in Phase III and if the direct costs faced by industrial sectors increase considerably over the 2021-30 time period.

The main output of this study was to provide an estimation of the distribution of preliminary free allocation in Phase IV across the higher emitting industrial sectors in order to determine the extent to which they may be short of free allowances relative to their direct emissions. For most sectors assessed, it was estimated that 65 % to 85 % of their direct emissions would still be covered by preliminary free allocation in Phase IV. It is important to acknowledge that this estimation is very conservative as it assumes no further abatement over the 2021-30 time period and moderate levels of annual growth in production that may be optimistic in light of the Covid-19 crisis and the uncertainty on future economic growth. The setting of the benchmark values is clearly the key input for determining levels of preliminary allocation by sector and changes to the benchmark values in 2026-30 based upon future technological progress could lead to a significant change in levels of preliminary allocation, which was not assumed within this modelling exercise. Indeed, the benchmark values used within this study will be subject to further change before they are finalised so the estimation of preliminary free allocation should be considered as also preliminary.

The final free allocation for each sector will depend upon the total preliminary free allocation not exceeding the free allocation budget for Phase IV. Within this study a range of scenarios were assessed so that the EU ETS could contribute to either a 50 % or 55 % overall reduction in GHG emissions below 1990 levels by 2030. The assessment highlighted several key variables beyond the ambition of the overall GHG target that ultimately influence the ETS cap including the share of effort between ETS and non-ETS sectors and how the tightening of the cap is implemented (e.g. either by an adjustment to the LRF or by rebasing the cap). Given that this study assumed that changes to the ETS cap would only take place from 2026 onwards (to take into account the political process for decision making), the more limited time frame meant that scenarios whereby the ETS cap was rebased (rather than increasing the LRF) were associated with higher levels of ambition. A key finding from the assessment was that due to the application of a buffer over Phase IV to supplement the free allocation budget, the CSCF was not triggered to a significant extent in the majority of the ETS cap scenarios assessed. The modelling exercise demonstrates that the implementation of the ETS cap is an important factor to consider along with the level of ambition when further tightening the ETS cap for Phase IV.

Given that it is likely that the majority of sectors will be short of allowances in Phase IV as a consequence of the enhanced level of ETS ambition in 2030, the study has also conducted a first order estimate of the abatement potential by selected sector that may reduce part of the expected shortfall in free allowances if options can be implemented at 'reasonable cost'. Due to the reliance upon information from literature, it was not possible to provide a consistent set of abatement potentials across sectors in this study and information on abatement costs were even more difficult to ascertain. However, considerable efforts have nevertheless been made to identify important abatement options and to harmonize assumptions on future uptake rates where possible. The assessment shows that BAT is likely to play an important role as an abatement measure for most sectors until 2030. More innovative abatement options such as the deployment of CCS and green hydrogen will have a more limited role to play until 2030. However, it is conceivable that the rate of uptake for such innovative technologies could increase more rapidly than assumed in this study with the introduction of strong policy incentives. It is evident from the assessment that further work will be required in the coming years to collect more accurate information on abatement potential and cost and that the participation of industry in this process will be vital in order to build consensus and to inform future policy decisions to better target financial support.

As the free allocation budget is set to decline further in 2021-30, it is of utmost importance that the remaining free allowances are targeted effectively in order to support the sectors most in need of carbon leakage protection. It was proposed in this study to therefore consider categorising sectors according to their vulnerability to carbon leakage that should reflect their specific circumstances. Indicators have initially been selected based upon the availability of consistent datasets across sectors. It is envisaged though that the list of indicators included in the framework proposed could be extended, for example, to also assess the profitability of a sector, if there is a consensus amongst industry on how best to derive such additional indicators in the future. The categories of carbon leakage vulnerability proposed in the framework suggest that the remaining free allocation should be prioritised for sectors associated with the manufacture of emission intensive products with a relatively high value to weight ratio. This could be achieved via the introduction of tiered allocation as a potential reform to the free allocation mechanism for Phase IV. However, for the majority of sectors, it is expected that alternative measures of support (e.g. introduction of consumption charges or provision of innovation funding) may also be effective in ensuring that industry in Europe remains competitive over the next decade and beyond whilst continuing to decarbonise.

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8. ANNEX

8.1. Availability of free allowances expected in Phase IV

The methodology for calculating the free allowances that are expected to be available in Phase IV to each sector assessed depends upon key input assumptions that are outlined in the following sub-sections.

8.1.1. Benchmark values

Table 8-1 provides an overview of the product benchmark values applied in order to estimate levels of free allocation in Phase IV of the EU ETS. Preliminary product benchmark values for the 2021-25 period were provided by DG CLIMA for use in this study. It was, however, necessary to assume values for the 2026-30 period as these values will be based on performance data that will need to be collected in the early stages of Phase IV before an update to the product benchmarks can take place. The following simple assumptions were applied in order to estimate product benchmark values for the 2026-30 time period:

- Product benchmarks are reduced by 0.2 % minimum and 1.6 % maximum annually compared to Phase III. For most product benchmarks the improvement has exceeded this range – so the product benchmark values are set at the maximum rate of -24 % (compared to Phase III values) in the years 2021-25 and it is then assumed for these product benchmarks that the maximum rate of -32 % (compared to Phase III values) is also applied for the years 2026-30. This includes the heat and fuel benchmark values;
- A number of product benchmarks showed improvements between the minimum/maximum – it was conservatively assumed that these product benchmark values remain constant in Phase IV. Implicitly this assumes no further improvement in performance even though the sectors have shown significant improvements in emissions performance in the past. In reality, it is expected that the benchmark value for these products would also decline between the 2021-25 and 2026-30 time periods;
- Four product benchmarks (i.e. primary aluminium, sintered dolime, steam cracking and soda ash) follow the minimum improvement rate (i.e. -3 % in 2021-25 and -4 % in 2026-30). Hot metal was an exception in the directive: the maximum reduction in 2021-25 is -3 %, then the actual reduction is applied.

It is important to acknowledge that the benchmark values in Table 8-1 are only provisional for the 2021-25 period and are only illustrative for the 2026-30 period based on the simple assumptions outlined in the bullet points above and do not reflect the final benchmark values for Phase IV. Indeed, it is likely for example that the ammonia benchmark will be revised upwards following a further assessment of the historic performance data. This would result in the allocation to the fertilizer sector being higher than what the results in this study show. For those products for which the benchmark based allocation calculation includes an adjustment for the exchangeability of fuels and electricity, the average adjustment factor for the 2014-18 time period has been derived from the NIMs dataset (European Commission 2020a). This is based on the exchangeability factor applied by each sub-installation using the relevant product benchmark, as an average weighted by activity level.

Table 8-1 Overview of the estimated product benchmark values applied in the study

Product benchmark	Unit	2013-20 BM	2021-25 BM	2026-30 BM	Adjustment factor for the exchangeability of fuels and electricity
Refinery products	EUA/t	0.0295	0.022	0.020	0.897
Coke	EUA/t	0.286	0.217	0.194	1.0
Sintered ore	EUA/t	0.171	0.142	0.142	1.0
Hot metal	EUA/t	1.328	1.288	1.235	1.0
EAF carbon steel	EUA/t	0.283	0.215	0.215	0.248
EAF high alloy steel	EUA/t	0.352	0.268	0.268	0.303
Iron casting	EUA/t	0.325	0.270	0.270	0.881
Pre-bake anode	EUA/t	0.324	0.246	0.220	1.0
[Primary] Aluminium	EUA/t	1.514	1.469	1.453	1.0
Grey cement clinker	EUA/t	0.766	0.689	0.689	1.0
White cement clinker	EUA/t	0.987	0.888	0.888	1.0
Lime	EUA/t	0.954	0.792	0.792	1.0
Dolime	EUA/t	1.072	0.965	0.965	1.0
Sintered dolime	EUA/t	1.449	1.406	1.391	1.0
Float glass	EUA/t	0.453	0.408	0.408	1.0
Bottles and jars of colourless glass	EUA/t	0.382	0.344	0.344	1.0
Bottles and jars of coloured glass	EUA/t	0.306	0.275	0.275	1.0
Continuous filament glass fibre products	EUA/t	0.406	0.309	0.309	1.0
Facing bricks	EUA/t	0.139	0.106	0.095	1.0
Pavers	EUA/t	0.192	0.146	0.131	1.0
Roof tiles	EUA/t	0.144	0.120	0.120	1.0
Spray dried powder	EUA/t	0.076	0.058	0.052	1.0
Mineral wool	EUA/t	0.682	0.566	0.566	0.726
Plaster	EUA/t	0.048	0.043	0.043	1.0
Dried secondary gypsum	EUA/t	0.017	0.013	0.012	1.0
Plasterboard	EUA/t	0.131	0.109	0.109	0.98
Short fibre kraft pulp	EUA/t	0.12	0.091	0.082	1.0
Long fibre kraft pulp	EUA/t	0.06	0.046	0.041	1.0
Sulphite pulp, thermo-mechanical and mechanical pulp	EUA/t	0.02	0.015	0.014	1.0
Recovered paper pulp	EUA/t	0.039	0.030	0.027	1.0
Newsprint	EUA/t	0.298	0.226	0.203	1.0
Uncoated fine paper	EUA/t	0.318	0.242	0.216	1.0
Coated fine paper	EUA/t	0.318	0.242	0.216	1.0
Tissue	EUA/t	0.334	0.254	0.227	1.0
Testliner and fluting	EUA/t	0.248	0.188	0.169	1.0
Uncoated carton board	EUA/t	0.237	0.180	0.161	1.0
Coated carton board	EUA/t	0.273	0.207	0.186	1.0
Carbon black	EUA/t	1.954	1.485	1.329	0.971
Nitric acid	EUA/t	0.302	0.230	0.205	1.0
Adipic acid	EUA/t	2.79	2.120	1.897	1.0
Ammonia	EUA/t	1.619	1.230	1.101	0.963
Steam cracking	EUA/t	0.702	0.681	0.674	0.933
Aromatics	EUA/t	0.0295	0.022	0.020	0.878
Styrene	EUA/t	0.527	0.401	0.358	0.935

Phenol/ acetone	EUA/t	0.266	0.202	0.181	1.0
Ethylene oxide / Ethylene glycol	EUA/t	0.512	0.389	0.348	0.821
Vinyl chloride-Monomer (VCM)	EUA/t	0.204	0.155	0.139	1.0
S-PVC	EUA/t	0.085	0.077	0.077	1.0
E-PVC	EUA/t	0.238	0.181	0.162	1.0
Hydrogen	EUA/t	8.85	6.726	6.018	0.957
Synthesis gas	EUA/t	0.242	0.184	0.165	0.844
Soda ash	EUA/t	0.843	0.818	0.809	1.0
Heat benchmark sub-installation, CL	EUA/TJ	62.3	47.348	42.364	1.0
Heat benchmark sub-installation, non-CL	EUA/TJ	62.3	47.348	42.364	1.0
District heating sub-installation	EUA/TJ	62.3	47.348	42.364	1.0
Fuel benchmark sub-installation, CL	EUA/TJ	56.1	42.636	38.148	1.0
Fuel benchmark sub-installation, non-CL	EUA/TJ	56.1	42.636	38.148	1.0
Process emissions sub-installation, CL	EUA/ t CO_2e	0.97	0.97	0.97	1.0
Process emissions sub-installation, non-CL	EUA/ t CO_2e	0.97	0.97	0.97	1.0

Note: Exchangeability of fuel and electricity i.e. products can be produced through either fuel- or electricity-driven processes. Indirect emissions from electricity consumption are not eligible for free allocation, therefore the share of indirect electricity emissions needs to be subtracted from the calculated free allocation. CL refers to carbon leakage.

Source: European Commission (2020a), own assumptions.

8.1.2. Activity rates

Table 8-2 provides an overview of the annual activity rates applied to historic activity rates reported in the NIMs dataset in the study in order to determine levels of free allocation in Phase IV of the EU ETS.

Table 8-2 Projected change in annual activity rates based on PRIMES modelling

Sector	Description and NACE 4-digit code	2019-25	2026-30
Iron and steel	Manufacture of basic iron and steel and of ferro-alloys (24.10)	-0.22 %	0.00 %
Refineries*	Manufacture of refined petroleum products (19.20)	0.00 %	0.00 %
Cement	Manufacture of cement (23.51)	0.56 %	0.42 %
Chemicals, except fertilizers	Industrial gases (20.11)	0.24 %	0.33 %
	Dyes and pigments (20.12)	1.04 %	0.92 %
	Other inorganic basic chemicals (20.13)	0.24 %	0.33 %
	Other organic basic chemicals (20.14)	0.24 %	0.33 %
	Plastics in primary forms (20.16)	1.04 %	0.92 %
	Synthetic rubber in primary forms (20.17)	1.04 %	0.92 %
Fertilizers	Manufacture of fertilisers and nitrogen compounds (20.15)	0.24 %	0.33 %
	Manufacture of pulp (17.11)	0.88 %	0.73 %

Pulp and Paper	Manufacture of paper and paperboard (17.12)	0.44 %	0.30 %
Lime	Manufacture of lime and plaster (23.52)	0.78 %	0.74 %
Non-Ferrous Metals	Precious metals production (24.41)	0.15 %	0.59 %
	Aluminium production (24.42)	0.80 %	0.38 %
	Lead, zin and tin production (24.43)	0.38 %	0.31 %
	Copper production (24.44)	0.45 %	0.44 %
	Other non-ferrous metal production (24.45)	0.15 %	0.59 %
Glass	Manufacture of flat glass (23.11)	0.62 %	0.68 %
	Shaping and processing of flat glass (23.12)	0.62 %	0.68 %
	Manufacture of hollow glass (23.13)	0.62 %	0.68 %
	Manufacture of glass fibres (23.14)	0.62 %	0.68 %
	Manufacture and processing of other glass, including technical glassware (23.19)	0.62 %	0.68 %
Ceramics	Manufacture of ceramics tiles and flags (23.31)	1.10 %	0.93 %

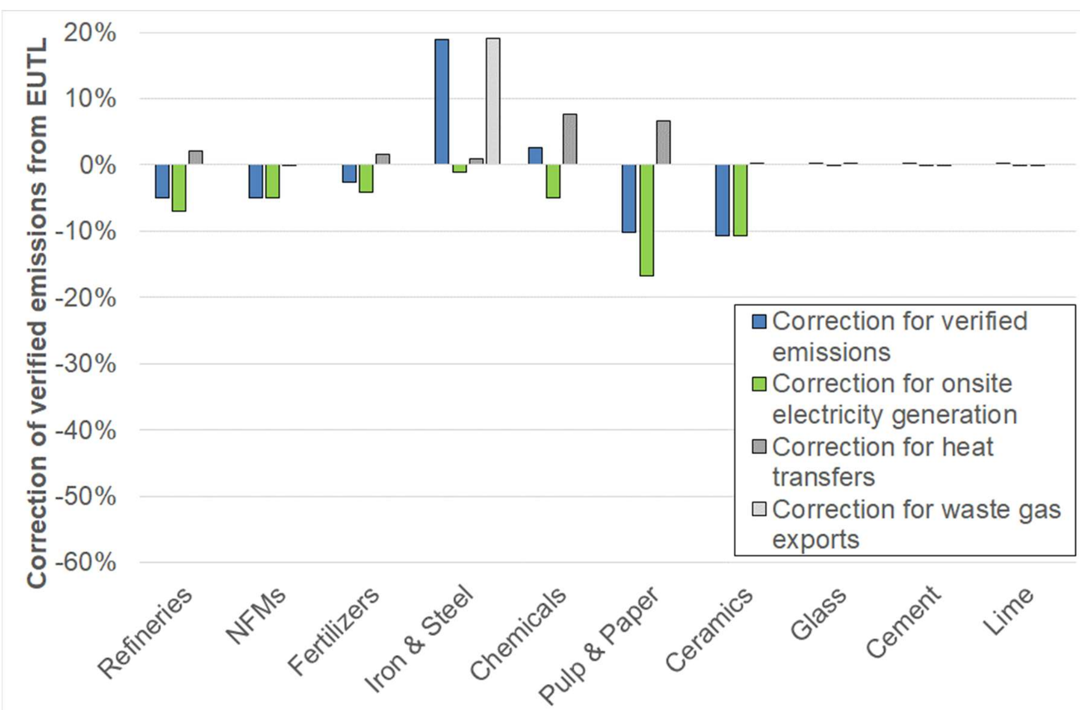
Note: Based on PRIMES projection not taking into account COVID-19 crisis. It was necessary to match the categories provided in the PRIMES modelling to the NACE 4-digit codes that were under consideration for the sectors in this study.
* Constant production for refineries assumed.

Source: PRIMES.

8.1.3. Correction of verified emissions

Figure 8-1 shows the correction of verified emissions for both onsite electricity generation and heat/waste gas transfers by sector. Most corrections to verified emissions are within 10 % of the average emission value reported in the EUTL, however the iron and steel, pulp and paper as well as ceramics sectors are notable exceptions.

Figure 8-1 Correction of verified emissions for onsite electricity generation and heat/waste gas transfers (2014-18 average)



Source: EUTL, European Commission (2020a).

The following sub-sections provide further information on the corrections to verified emissions that were undertaken.

8.1.3.1. Electricity and heat transfers (all sectors)

Free allocation based on product benchmarks refers to the product produced. Electricity generation does not receive free allocation. Therefore, emissions related to electricity produced within the installation are deducted based on NIMs information.

As opposed to the rule for electricity, installations do receive free allocation for heat produced within the same installation but also if imported from other ETS installations and/or exported for district heating purposes or non-ETS entities. Therefore, emissions related to allocation relevant heat flows are added in the case of imports from other ETS installations and deducted when exported to ETS installations. Emission data stems from the NIMs.

8.1.3.2. Iron and steel: Waste gas transfers

Given that some steel works transfer their blast furnace gases to power plants that generate electricity for the grid, emissions caused by the combustion of these blast furnace gases were added in this assessment. The amount of emissions that were added relates to the net export of waste gases to installations that are outside of the NACE code 24.10. This information was extracted from the NIMs dataset. When the emissions related to the waste gas transfers were reported, this information was used. When only the energy content was reported, average emission factors were used to calculate emissions based on information in the NIMs from installations that reported both emissions and energy content. The emission factor that was calculated for each year was volume weighted to account for installations producing different waste gases (i.e. blast furnace gas, basic oxygen furnace gas and coke oven gas), as these waste gases are with different emission factors.

Given that electricity generation does not receive free allowances, a further deduction was made to this emission factor (that was equivalent to natural gas) so that any waste gas used for electricity production did not receive free allowances.

8.1.3.3. Pulp and paper: Biomass use

The pulp and paper sector is characterised by a large share of biomass input as well as substantial electricity exports. Following the standard rule outlined above would result in deducting more emissions than would be realistic. Therefore, a deviating approach was adopted: Whereas for the other sectors implicitly a natural gas emission factor was assumed, in the pulp and paper sector the share of biomass emissions in total emissions (both stemming from fossil sources and biomass) was calculated based on NIMs information. In the pulp sector the share of biomass was 94 % on average and in the paper sector 57 %. This fraction was deducted from emissions related to electricity generation within the sector.

Deduction of verified emissions would have been higher if it was assumed that all onsite electricity was produced from natural gas. Alternatively, no emissions would have been deducted for onsite electricity generation if biomass was the only fuel input. The fuel input from biomass is a key variable influencing verified emissions and this makes the results for the sector less certain than the results of the other sectors assessed.

8.2. Abatement potential and costs identified over the sectors

8.2.1. Literature

The literature used within the study for estimating abatement potentials is outlined for each sector in Table 8-3.

Table 8-3 Sources of data for estimating sector abatement potentials

Sector	Industrial Innovation study	Other sources
Iron and Steel	BAT, Biocycle and 4b 95% max scenario	Not applicable
Cement	BAT and 4b 95% max scenario	Cembureau (2018)
Chemicals	BAT scenario and 4b 95% max scenario	DECHEMA (2017)
Refineries	Not applicable	Concawe (2019), FuelsEurope (2018)
Fertilizers	BAT and CCS scenario	FertilizersEurope (2018)
Pulp and Paper	BAT scenario and 4b 95% max scenario	Fleiter, et al (2012); DNV (2015)
Non-ferrous metals	BAT scenario and 4b 95% max scenario	Not applicable
Glass	Not applicable	DECC (2015), Glass Alliance Europe (2019), Glass for Europe (2020), EC (2013, 2019)
Ceramics	BAT scenario and 4b 95% max scenario	Not applicable
Lime	BAT scenario and 4b 95% max scenario	Not applicable

Source: Own illustration.

8.2.2. Best available techniques (BAT)

BAT refers to abatement measures with high technology readiness level and market maturity, already being adopted in some industrial facilities, but not widely implemented yet. Since this assessment largely builds on the work previously undertaken in the ICF and Fraunhofer ISI (2019) study, the same definition of BAT is applied in each sector where some of the measures that fall under BAT could be considered as innovative/advanced measures. It is important to highlight that the BAT scenario also accounts for incremental emissions reductions in the reference scenario. Given that BAT & process innovation accounts for a large share of the abatement potential identified in all of the sectors assessed, Table 8-4 provides an overview of the key abatement options considered under this category.

Table 8-4 Description of BAT & process innovation abatement options

Sector	Abatement options
Iron and Steel	Optimization of coking and sintering process, optimization of basic oxygen furnaces and EAFs, increased share of secondary steel and EAF deployment, heat recovery options.
Cement	Energy efficiency improvements and fuel switching to renewable energy sources.
Chemicals (excluding fertilizers)	Improving reaction conditions (e.g. optimization of heating coils, waste heat recovery, advanced furnace materials), and improving the separation process.
Refineries	Energy management systems, intra-unit and inter-unit integration and heat transfer and upgrading of low-grade heat.

Fertilizers	Optimization of heating coils, integrated gas turbines with furnace; low grade waste heat recovery; and advanced furnace material (ceramic fibres). Catalytic reactors in nitric acid production (in addition to Fraunhofer study).
Pulp and Paper	Improving energy efficiency, alternative fuel use and electrification of steam generation.
Non-ferrous metals	Aluminium: Reduction of emissions in the Bayer process by converting to natural gas as a fuel instead of oil boilers, using fluidised bed calcination process and tube digesters, optimization of the refining process and CHP and waste-heat co-generation. Reduction of emissions in the electrolysis process (H-H process) using process optimization techniques, novel designs for anodes, heat recovery from H-H off gases. Reduction of emissions from downstream aluminium; magnetic billet heating (downstream process); secondary re-melting of scrap aluminium. Copper: Reduction of GHG emissions through flash smelting, using Outokumpu process and oxygen flash technique; waste heat recovery boilers; magnetic billet heating.
Glass	Oxy-fuel combustion (BAT). Increased share of secondary glass. Glass batch reformulation. Batch pelletisation.
Ceramics	Improving energy efficiency in drying and firing processes, as well as raw materials optimization.
Lime	Improving energy efficiency by adopting fuel saving measures, insulation of furnaces, process control as well as converting horizontal kilns to Parallel flow regenerative kilns (PFRK), use of waste heat, and applying electrical savings measures.

Source: Own illustration.

8.3. Options for addressing leakage in vulnerable sectors

Table 8-5 provides an example of the tier for each sector based upon a targeted approach using updated leakage indicators.

Table 8-5 Targeted approach using updated leakage indicators

Sector	Description and NACE 4-digit code	Leakage indicator (Phase 4)	Tier (based on Option 4 of the 2015 impact assessment)
Iron and steel	Manufacture of basic iron and steel and of ferro-alloys (24.10)	2.121	High
Refineries	Manufacture of refined petroleum products (19.20)	3.222	Very high
Cement	Manufacture of cement (23.51)	2.455	High
Chemicals, except fertilizers	Industrial gases (20.11)	1.021	High
	Dyes and pigments (20.12)	0.519	Medium
	Other inorganic basic chemicals (20.13)	1.638	High
	Other organic basic chemicals (20.14)	1.049	High
	Plastics in primary forms (20.16)	0.312	Medium
	Synthetic rubber in primary forms (20.17)	0.604	Medium
Fertilizers	Manufacture of fertilisers and nitrogen compounds (20.15)	2.418	High
	Manufacture of pulp (17.11)	0.987	Medium

Pulp and Paper	Manufacture of paper and paperboard (17.12)	0.836	Medium
Lime	Manufacture of lime and plaster (23.52)	1.021	High
Non-Ferrous Metals	Precious metals production (24.41)	0.092	Low
	Aluminium production (24.42)	1.632	High
	Lead, zin and tin production (24.43)	1.031	High
	Copper production (24.44)	0.421	Medium
	Other non-ferrous metal production (24.45)	0.280	Medium
Glass	Manufacture of flat glass (23.11)	1.457	High
	Shaping and processing of flat glass (23.12)	0.066	Low
	Manufacture of hollow glass (23.13)	0.631	Medium
	Manufacture of glass fibres (23.14)	0.417	Medium
	Manufacture and processing of other glass, including technical glassware (23.19)	0.228	Medium
Ceramics	Manufacture of ceramics tiles and flags (23.31)	1.049	High

Source: Own illustration.

8.4. Webinar with relevant stakeholders

The project team was planning to hold a full-day technical workshop in Brussels; inviting the relevant stakeholders to attend the meeting to present the main findings of the study. However, due to the pandemic, the full day workshop was replaced with an online webinar using Zoom as the webinar platform. The webinar took place on the 22nd of October 2020 from 09:30 h until 13:30 h. We identified the relevant stakeholders, together with DG CLIMA, as follows:

- European Industry Associations and key industry players (of the sectors covered in the study);
- Representatives of different Directorate Generals – European Commission;
- European non-governmental organizations that are active on industrial decarbonisation, EU ETS and carbon leakage topics.

The online webinar was organised by Trinomics; chaired by Hans Bolscher and supported by all the project team members in each Q&A session. Invitations were sent to the relevant stakeholders on the 5th of October 2020, with registration links to register the webinar attendance. Participants were allowed to raise questions during the webinar via the chat box, and these questions were recorded and immediately addressed in each Q&A session. The following agenda shown in Table 8-6 was followed for the webinar. The presentations used during the workshop were sent to the webinar attendees through e-mails on 28th of October 2020. The project team tried to address the comments/feedback received from the relevant stakeholders on the findings of the study to the extent possible in this synthesis report. During this project's course of work, the consultants used, whenever possible, publicly available data (from Eurostat and the ETS process) and results from previous studies that had already been commented by industry. Therefore, the webinar was indeed the main input possibility for all stakeholders.

Table 8-6 Webinar agenda

Timing	Agenda Item
09.15 – 09.30	Opening the platform
09.30 – 09.35	Welcome by the Chair (Hans Bolscher) and explanation of the agenda and options for participation in the meeting
09.35 – 09.50	Presentation from DG CLIMA ○ Why this research? ○ How does it fit in overall progress and Green Deal? What will be done with the outcomes?
09.50 – 10.05	Q&A on the presentation from DG CLIMA
10.05 – 10.15	Overall methodology to assess vulnerability of sectors to carbon leakage (Öko-Institut)
10.15 – 10.30	Availability of free allowances expected in Phase IV (Öko-Institut / Ricardo) ○ Methodology ○ Key results
10.30 – 10.50	Q&A
10.50 – 11.10	*Coffee/Tea break*
11.10 – 11.40	Abatement potential identified over the sectors (Trinomics) ○ Methodology ○ Key results
11.40 – 12.10	Q&A
12.10 – 12.20	Vulnerability to carbon leakage based on sector characteristics (Öko-Institut / Adelphi / Trinomics) ○ Methodology ○ Key results
12.20 – 12.50	Q&A
12.50 – 13.05	Options for addressing carbon leakage in vulnerable sectors (Adelphi) ○ Methodology ○ Key results
13.05 – 13.25	Q&A
13.25 – 13.30	Next steps by DG CLIMA and closure

Source: Own illustration.

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