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Article

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Lessons from the EU ETS

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Introduction

Most Europeans have noticed that the number of windmills that dot the landscape has increased sharply over the past decade. Streets without at least a couple of houses covered by solar panels have become hard to find. The increasing use of renewable energy sources (RES) is arguably the most visible result of Europe's ambition to become climate neutral by 2050. A factor less familiar to the general public, though it is a key policy instrument of the EU's greenhouse gas (GHG) mitigation strategy, is the European Union Emissions Trading System (EU ETS). This system forces large industrial installations to pay for at least a part of their CO_2 emissions. It covers approx. 39 % of total EU greenhouse gas (GHG) emissions. The EU ETS does not only give a financial incentive for the adoption of RES but also stimulates the emission-intensive manufacturing sector to reduce its carbon footprint.

Supporters of the EU ETS point out that it has certainly delivered on its promises. The emission reduction target for the period 2005 to 2020 was already reached in 2014.[1] Looking beyond the overall EU ETS emissions, however, it is clear that the reductions were predominantly driven by the electricity generation sector (Marcu *et al.*, 2021), which has substantially reduced its carbon intensity.[2] Previous studies show that this was certainly not achieved solely by the adoption of new technologies but also by switching to less carbon-intensive fossil fuels (see Teixidó *et al.*, 2019, for an overview). This is best described as coal-to-gas switching.[3] Whether or not the substantial reductions in emissions from the electricity generation sector (and by extension the emissions covered by the EU ETS) are due to the EU ETS or rather to other policies remains debated.[4] One can, however, safely say that the EU ETS played at least a supporting role in the reduction of emissions, including outside the power generation sector.[5]

1 When considering current ETS scope for allowances and emissions. See https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1, the targeted emission reduction between 2005 and 2020 was 21 %.

2 According to the European Environmental Agency (EEA), the EU27+UK countries reduced their GHG emission intensity of electricity generation from 394 gCO_2-eq/kWh in 2005 to 250 gCO_2-eq/kWh in 2019.

3 This involves a reduction in emissions for the same volume of electricity produced, but heightens the sector's dependence on the contingencies of the current natural gas supply.

4 See Marcu *et al.* (2021) for an overview of the literature. Studies that find a causal reduction in emissions driven by the EU ETS generally focus on the period 2008-2012. This early positive effect of the EU ETS might well be attributable to securing easy wins rather than an indication of a deeper decarbonisation trend.

5 Colmer *et al.* (2022) find that French ETS regulated manufacturing firms reduced carbon emissions by 8-12 % compared to unregulated firms. De Jonghe *et al.* (2020) observe that emission trading schemes do improve the emission efficiency of highly polluting firms.

If the overall emission reductions of the EU ETS were largely driven by the electricity generation sector, this implies that the manufacturing sector's emission reduction efforts (or the result of those efforts) remained limited. This observation has already been made by Vieira *et al*. (2021). They conclude that the past EU ETS performance might well produce a false sense of an economy in transition. And a transition will certainly be needed, not only because the EU ETS enforced cap on emissions will be cut further to reach net zero before 2050 according to the European Green Deal [1], but also to avoid the negative consequences of climate change. A far-reaching transformation of the carbon-intensive manufacturing sector is hence a must.

A possible explanation for the difference in carbon reduction performance between the electricity generation sector and manufacturing sector is a differential regulatory pressure (Bel and Joseph, 2018, Vieira *et al.*, 2021). Whilst the manufacturing sector receives a sizable part of its emissions rights for free, the electricity generation sector does not. [2] Furthermore, many European countries have a wide range of subsidies available for the installation of RES. In addition to the regulatory drivers, it must not be overlooked that carbon-free technologies for electricity generation are known and already implemented on a large scale. For manufacturing industry, however, there currently remains uncertainty on what technologies should be adopted and what their actual potential is for carbon abatement (Gerres *et al.*, 2019). Nevertheless, several authors [3] have pointed out that carbon-intensive industries could potentially suffer from a so-called "carbon lock-in" where a combination of institutional, economic, legal and even cultural factors prevent their transition to low carbon alternatives.

Analysis of the debate on how to achieve climate neutrality plainly reveals the focus on green innovation. The European Commission (EC) intends its new Industrial Strategy for Europe to lead Europe's manufacturing firms to a carbon neutral future while making them more globally competitive. It intends to *"help industry to reduce their carbon footprint by providing affordable, clean technology solutions and by developing new business models"*. [4] The focus is clearly on developing innovative technology and processes and ensuring their adoption across Europe. Whilst we do not doubt the importance of green innovation, this strategy implicitly follows the view that the necessary technology to enable Europe's manufacturing industry to start its deep decarbonisation process is not yet available. The complex system that the EU ETS uses to distribute free emission rights amongst industrial installations, however, is based on a benchmark set by the best performing installations producing a similar product. It hence acknowledges that there is a certain dispersion in carbon performance within narrowly defined sectors. More specifically, Vieira *et al.* (2021) study the progress of EU ETS emissions and find that manufacturing firms performing the same activities presented results ranging from no reduction to more than 80 % of emissions abated over the period 2005-2017. They therefore conclude that the lack of alternative technologies cannot be the sole reason for poor mitigation results.

Suitable strategies for reaching the ambitious goals for emissions reductions by European industry require a comprehensive understanding of emissions reductions achieved in the past. In this article we therefore explore another way of improving the aggregate carbon efficiency of the manufacturing sector in addition to improvements or innovation within firms. This involves reallocation or the shift of resources between firms and industries. The importance of reallocation for aggregate productivity gains is well established since the seminal work from Foster *et al.* (2001). They found that this mechanism accounts for around 50 % of productivity growth in US manufacturing and 90 % in the retail sector. Other authors have found comparable results for Europe and Belgium. When resources are shifted from low to high productivity firms, aggregate productivity rises without increases in the underlying productivity of individual firms. A similar reasoning applies to gains in carbon efficiency. Carbon emissions can be reduced by a change in production techniques or by investment in abatement on the part of existing firms (i.e. innovation). In addition, emissions can also be reduced by

1 The European Green Deal is a set of policy initiatives taken by the EC with the aim of making Europe the first climate neutral continent in the world.

2 Note that standard economic theory predicts that, in the absence of transaction costs, the outcome remains the same independent of how the emissions rights are initially distributed.

3 E.g., Janipour *et al.* (2020) for the Dutch chemical industry, Chiappinelli *et al.* (2021) for the European basic materials sector, Koasidis *et al.* (2020) for the UK and German iron and steel, cement and chemicals industries.

4 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/industry-and-green-deal_en.

reallocation. Reallocation refers to resources that are redistributed, within industries, towards relatively more carbon efficient firms, through the exit of the most carbon-intensive incumbents and the entry and growth of cleaner firms.

We find that manufacturing industry has not substantially decreased its emissions over the past decade. The emission intensity, or emissions vs. turnover did not decline substantially either. Within-firm changes or innovation did not sizably decrease the overall emission intensity. For the individual sectors, the contribution of innovation is mixed. Only in the metals, glass and ceramics, and paper industry did individual firms become more carbon efficient and reduce their intensity. Reallocation did not reduce emission intensity either. Only in the chemicals industry did the most carbon efficient firms gain market share and reduce the average emission intensity. For all other sectors the most efficient firms did not gain market share. However, we do find carbon returns to scale in all sectors. This means that growing firms become more carbon efficient and reduce their emission intensity. For future reductions, besides within-firm improvement and technological change, there is still potential for reducing emissions by moving output to the cleanest firms within a given sector. We find that a limited reallocation within a sector and away from the most emission-intensive firms could result in a ~40 % emission reduction across the EU. Increasing carbon prices may drive reallocation but this will not necessarily be the most effective strategy. This implies that a wider mix of policies will be needed to ensure the timely decarbonisation of manufacturing industry.

The article is organised as follows: we first introduce the EU ETS and its underlying principles. Section 2 describes the data we use. Section 3 breaks down the overall EU ETS emission by sector and country. Section 4 studies emission intensities or the trend in emissions relative to output. Section 5 then digs into the underlying drivers of these changes and decomposes them into within-firm innovation, between-firm reallocation, entry and exit. Section 6 investigates the potential of reallocation for future emission reductions and Section 7 assesses to what extent an increased carbon price could encourage reallocation. The final section concludes.

1. The European Emissions Trading System (EU ETS)

1.1 Increased European commitments to reduce GHG emissions

Since its inception in 2005, the EU ETS represents an ambitious attempt to combine economic growth and welfare enhancement with the reduction of GHG emissions from emission-intensive processes, both within the power generation sector and in the manufacturing sector. The EU ETS is a key policy of the EU's overall pledge to reduce GHG emissions. The EU engagement in reducing its GHG emissions is not new, and Member States already agreed to act in 1992 at the World Summit in Rio de Janeiro and later with the adoption of the Kyoto protocol of 1997. Since then, increasingly stronger commitments, including binding emission reduction targets, have been adopted to tackle the global climate change issue. Both production and consumption patterns are concerned and should be guided by effective and credible goals. In 2020 the EC put forward a further cut in its net GHG emissions from 40 % to at least 55 % (compared to 1990 levels) by 2030 as a mid-term climate target to set the EU on a responsible path to become climate neutral by 2050. It mobilises actions across all sectors to reduce the EU's GHG emissions with contributions from citizens, companies and authorities.

The policies put in place are organised around three pillars. The emission-intensive industry and power sectors are covered by the EU ETS and relate to electricity and heat production, industry and aviation. These sectors accounted for close to 40 % of emissions in 2019 and are subject to carbon pricing through the cap-and-trade of emission rights at EU level. The remaining activities are subject to the Effort Sharing Regulation (the so-called ESR sectors) and include agriculture (17 % of ESR emissions), road transport (35 %), small industrial installations (16 %), buildings (25 %) and waste (5 %). This regulation sets binding national targets for annual GHG emission reductions over the period 2021-2030. Member States have to deliver national energy and climate plans which describe their intended measures and the policies to be implemented to reach the proposed targets.

Finally, the land use, land use change and forestry (LULUCF) sector is requested to manage land and forestry so as to preserve and expand the natural carbon (net) sink. To fulfil the "no-debit" rule, Member States have to ensure that accounted emissions (debits) from all categories within the LULUCF sector do not exceed accounted removals (credits) from 2021 to 2030 (i.e. net carbon sink maintained).

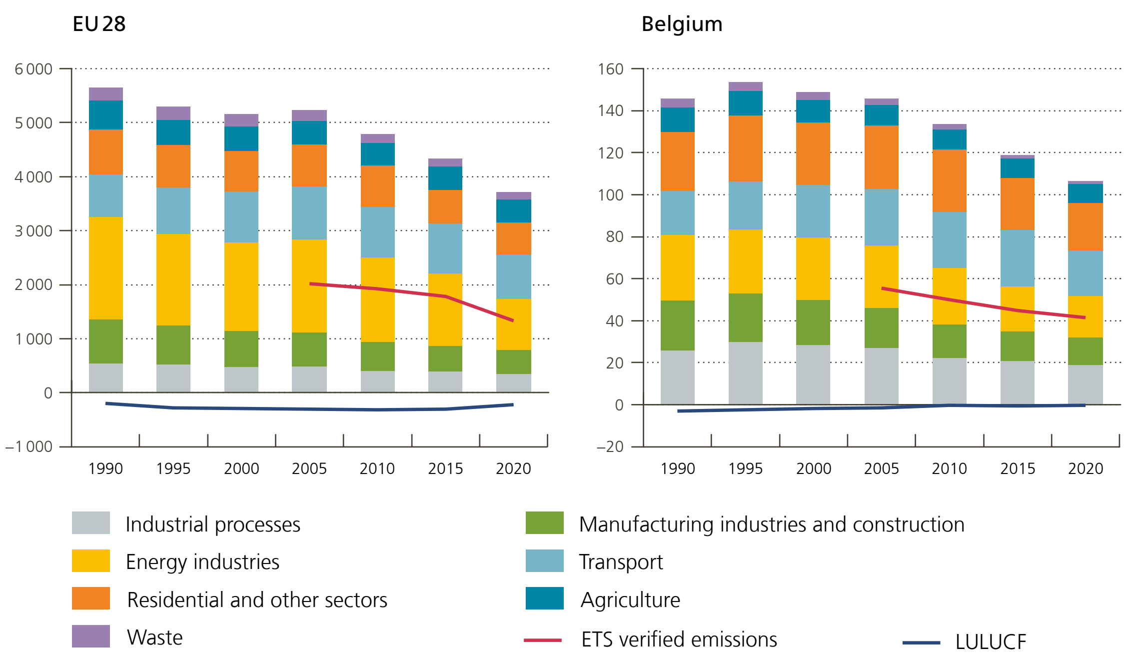
Proposals are under discussion as part of the "Fit for 55" legislative package prepared by the EC to accelerate emission reductions, on which the European Council adopted a common position in June 2022. For its part, the European Parliament agreed the revision of the EU ETS, raising the ETS target from 61 % to 63 % by 2030, and confirmed the increase from 30 % to 40 % emission reductions at EU level for the ESR sectors (translated into a target increase from 35 to 47 % for Belgium). Regarding the LULUCF sector, it is proposed to set the overall Union target of net GHG removals to –310 million tCO_2-eq by 2030 and to achieve climate neutrality in the combined LULUCF and agriculture sectors by 2035 at EU level. This would de facto raise the EU's 2030 GHG reduction target to 57 % according to the European Parliament's stance.

Actually, since 1990 EU28 GHG emissions (excluding LULUCF) decreased by 1 928 million tCO_2-eq or –34 % up to 2020 (and –28 % up to 2019). The reduction varied across emission sources, with the biggest reduction in energy use by manufacturing and energy industries (electricity producers) as well as in non-energy use (as feedstock) in industrial processes. It largely concerns ETS regulated installations. Emissions from residential heating have been reduced by 27 % while no progress has been achieved regarding emissions due to transportation (+3 %). Belgian emissions have been reduced by 39 million tCO_2-eq or 27 % less than in 1990 (and 2005): progress from residential sources and industries has been less marked than at European level except in the case of manufacturing industries. Emissions linked to industrial processes are more pronounced while the lower shares of energy industries' emissions reflect the use of some carbon-free nuclear energy for electricity production. Transportation-linked emissions have not improved.

Chart 1

European and Belgian emissions by source

(emissions by source and verified emissions of ETS stationary installations, in million tCO_2-eq)



Sources: EU ETS data viewer, OECD.

1.2 The EU ETS regulates emissions of large installations via a cap-and-trade mechanism

The EU ETS system imposes a decreasing cap on the emissions of the so-called regulated installations[1] for the equivalent of which EU emission allowances (EUAs) are made available by auction, and partly for free. These emission rights are tradable: installations emitting more than their allocation must purchase the equivalent of allowances; those emitting less than their allocation can resell unused allowances through bilateral transactions or on the secondary exchange traded marketplaces (the German EEX, ICE Endex in the Netherlands and Nasdaq Oslo in Norway) to finance low-carbon investment, or they can bank them for future use. Within the cap, companies must reduce their emissions and trade EUAs at the carbon price set on the markets in order to achieve GHG emission reductions at least cost.

Several reforms have been introduced to correct inefficiencies and to adapt the mechanism's design to higher ambitions. The system has been adjusted in four phases in terms of scope, cap level and allocation conditions. In addition to the EU27 founding countries, Liechtenstein, Norway, Iceland and Croatia have adhered to EU ETS while the United Kingdom has withdrawn and put in place its own system after Brexit. Since 1 January 2012 the emitting sectors concerned have been extended to include aviation within the European Economic Area, although it

1 Or entities with compliance obligations i.e. companies and aircraft operators required to participate in the EU ETS.

Table 1

Increasingly stringent EU ETS requirements through the different phases

Scope	Phase 1 (2005-2007)	Phase 2 (2008-2012)	Phase 3 (2013-2020)	Phase 4 (2021-2030)
Geography	EU27	+ Liechtenstein + Norway + Iceland	+ Croatia	– UK[1] (except for power plants in Northern Ireland)
Sectors	Power stations and other combustion plants ≥ 20 MW, Oil refineries, Coke ovens, Iron and steel plants, Cement clinker, Glass, Lime, Bricks, Ceramics, Pulp, Paper and board	+ Aviation (from 2012)	+ Aluminium, Petrochemicals, Ammonia, Nitric, adipic and glyoxylic acid production Carbon capture and storage	
GHGs	CO_2	+ N_2O (by some Member States)	+ PFC from aluminium production	
Cap	Set on the basis of estimates – no reliable emissions data Non-compliance penalty of € 40/tCO_2	Set bottom-up Non-compliance penalty of € 100/tCO_2	EU-wide cap – 2013: 2 084 million tCO_2-eq LRF 1.74 % = 38.3 million tCO_2/y Non-compliance penalty of € 100/tCO_2 adjusted for inflation	2021: one-off reduction to 1 576 million tCO_2-eq LRF 2.2 % = 43 million tCO_2/y
Allocation procedure	According to historical emission levels – mostly for free National registries	According to historical emission levels – mostly for free	Auctioning and for free (according to benchmarks) No longer free EUAs for power plants	Auctioning and for free: 100 % if significant risk of carbon leakage If not: based on benchmarks adjusted for technological progress + phased out to 0 by 2030

1 According to Refinitiv, as a net contributor to the market surplus in the EU ETS following relatively substantial emission cuts especially in the British power sector, the removal of the UK makes the EU ETS market 750 million tCO_2-eq tighter for the 2021-2030 period.

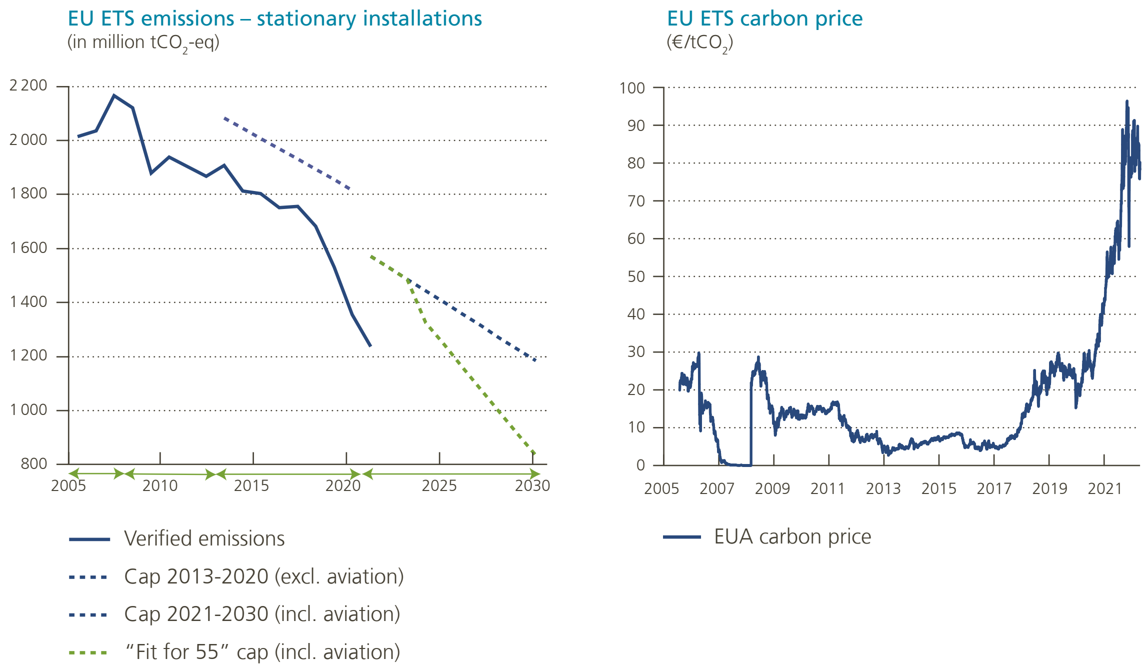
has its own allowances (EUAAs) and a separate auction. In 2013, CO_2 emissions from the petrochemical, ammonia, and aluminium production sectors have been considered as well as nitrous oxide (N_2O) and perfluorocarbon (PFC) emissions and those linked to carbon capture and storage projects.[1] In Phases 1 and 2, emission caps were set by a bottom-up approach which resulted in a surplus in the availability of EUAs. In 2013 a single EU-wide cap was determined, decreasing annually by a linear reduction factor (LRF) expressed in % of the average total quantity of EUAs issued annually in 2008-2012. Since then, power plants have no longer received free allowances. In today's 4th phase, the LRF has been increased from 1.74 % (38.3 million tCO_2-eq/y) to 2.2 % (43 million tCO_2-eq/y). Allocation procedures have also been strengthened: while in Phases 1 and 2, allowances were allocated according to historical emission levels – which tended to preserve the status quo –, there was a shift from grandfathering to a combination of auctioning and free allocation. 57 % of allowances were auctioned on the primary market. Remaining allowances were given for free according to benchmarks: installations that met these benchmarks received the corresponding allowances, while installations that did not received free allowances up to 80 % of benchmarks. This percentage was gradually lowered from 80 % of the benchmarks in 2013 to 30 % in 2020, except in sectors deemed to be at significant risk of carbon leakage (i.e. on the carbon leakage list). From 2021 onwards, the free allocation remains if there is a significant risk of carbon leakage. For the less exposed sectors, allocation rules are based on historical production levels and technical product benchmarks which will be updated twice to reflect technological progress since 2008. For installations that are not on the carbon leakage list, free allocations are set to be phased out after 2026 from a maximum of 30 % to 0 % at the end of Phase 4 in 2030.

Since its inception, the EU ETS price has remained at low levels primarily due to a surplus in the availability of EUAs above the level of verified emissions. Phase 1 is to be considered as a pilot phase with generous national allocation schemes, where almost all EUAs were given for free. As the allowances could not be banked for

1 EUAs need not be surrendered where CO_2 is successfully captured and stored (i.e. in accordance with the framework established by the EU CCS Directive); those emissions will be considered as "not emitted".

Chart 2

Emissions stayed well below the cap while the carbon price recently rallied



Sources: EC, Refinitiv (an LSEG company).

the next phase, the EUA price fell to zero in 2007. Phase 2 was marked by the 2008 economic crisis and accordingly unexpected (large) emission reductions and a large surplus of allowances. Many changes were introduced in Phase 3, with auctioning as the default method for allocating EUAs, while harmonised allocation rules were defined for free allowances. However, during the period 2013-2017, and despite the adoption of an EU-wide cap, surplus EUAs were accumulated in holding accounts and the price did not exceed € 9/tCO_2-eq, too low to justify green investments. Several reforms were undertaken to support the price signal: the postponement – backloading – of the auctioning of 900 million EUAs until 2019-2020 (subsequently transferred to the reserve instead of being released for auction), the setting up of the Market Stability Reserve (MSR)[1] and the revision of the functioning rules for Phase 4. These measures have driven the price up as they have influenced how market players expect the price to move (adjustment of the supply and increased demand due to the announced phasing-out of free allocations).

Upcoming reforms to the EU ETS as part of the "Fit for 55" legislative package are supporting a tighter carbon market. According to the July 2021 EC proposal for reaching the 2030 emissions reduction target, the EU ETS will be extended to international shipping and an adjacent ETS will be introduced to cover emissions from fuel use in road transport and building (regulation at fuel suppliers' level). A further tightening of available EUAs is foreseen with a one-off reduction of the overall emissions cap by 117 million EUAs ("re-basing") and a steeper annual LRF of 4.2 % to ensure that the decrease will result in a 61 % reduction in ETS emissions by 2030 compared to 2005. Free allocation is made conditional on decarbonisation efforts: installations covered by the obligation to conduct an energy audit (under the Energy Efficiency Directive) will be required to implement the audit report recommendations, or to demonstrate the implementation of other equivalent measures. As an alternative measure to mitigate carbon leakage risks, a Carbon Border Adjustment Mechanism (CBAM) will be phased in over 2026-2035 and will put a price on the carbon content of imports of a targeted selection of products. Sectors covered by that measure should therefore not receive any free allocation, which is to be phased out by 2030. Benchmark values will be adapted to ensure faster incorporation of innovation and technological progress.

In June 2022, the European Parliament decided on an even tougher reform of the EU ETS and the CBAM. Members of the European Parliament agreed on a one-off cut to the EU-wide quantity of allowances in circulation, in combination with an increase in the LRF from 4.2 % to 4.4 % until the end of 2025, rising to 4.5 % from 2026 and to 4.6 % from 2029, which will allow attainment of the (higher) ETS emissions reduction target of 63 % by 2030. Free CO_2 emission allowances will be phased out from 2027 and disappear by 2032. They will be replaced by the CBAM system from 2027 onwards. For its part, the European Council has conformed to the EC's initial proposals despite the postponement of the implementation of certain measures and a number of temporary exceptions (allowances would be put back into circulation in the event of an excessive increase in carbon prices).

These ongoing reforms to the EU ETS as part of the "Fit for 55" legislative package are aimed at a tighter market with fewer EUAs made available to it, which will affect all ETS installations. The enlarged range of activities subject to the EU ETS and the reduction in allowances should sustain the carbon price levels required to stimulate innovation and low-carbon investments across firms. Indeed, the further adoption of carbon-free processes in carbon-intensive industries remains vital to achieve the transition.

1 The MSR mechanism is a predefined rule-based scheme that reduces the historical allowances surplus and adjusts the number of EUAs to be auctioned according to the market surplus, and hence regulates the quantity of allowances in circulation over the long term: as long as this surplus is above 833 million EUAs, 24 % of it will be put in the MSR (12 % as of 2024) and from 2023 the EUAs exceeding previous year auction volumes will be cancelled from the MSR.

2. Measuring GHG emissions at the firm level

The analysis in this article is based on linking installation-level GHG emission data from the EU ETS with firm-level financial and employment data from Bureau Van Dijk's ORBIS database. Amongst other things, this allows us to track firm-level emission intensity, i.e. emissions relative to output.

We start from the European Union Transaction Log (EUTL), the central reporting and monitoring system for all EU ETS transactions. As the EUTL is not easily accessible we use the EUETS.INFO interface described in Abrell (2021) to access the data. The EUTL includes the actual yearly emissions and freely allocated emissions at the installation level. We exclude emissions from the aviation sector and only use information on stationary installations.

The EUTL also gives a national company registration number and company name that links the installation to its corporate operator company. We use this registration number to match the installation with a company in Bureau van Dijk's ORBIS database. Where a direct match was not possible, we use ORBIS's fuzzy search based on the installation owner's name. In the event of multiple results, we manually selected the most feasible match. ORBIS gives for each company the typical balance sheet and profit and loss statement as well as employment figures and the company's activity (NACE code).

The EUTL also states an activity for each installation. The activity is either linked to a sector (e.g., chemicals, metals) or to "combustion". A combustion installation generally refers to an installation that uses heat to generate electricity and consequently most of them are operated by companies in the utilities sector. However, a combustion installation may also belong to a manufacturing company or a services company or organisation (e.g., hospitals, universities). Combustion installations are allocated to a sector based on the NACE code of the installation's operator company.[1] If a combustion installation cannot be attributed to a specific sector, it is regarded as part of the utilities sector. All installations for which the operator company has a NACE code between 35 and 39[2] are attributed to the utilities sector.

Section 3 only makes use of emissions at the installation level and hence includes all stationary installations for which the EUTL reports emissions. From section 4 onwards, individual installations are aggregated, within a country, to the company operating the installation. If a single company operates multiple installations with a different activity, we take the activity that represents the most emissions as the activity for the whole firm. In addition, we were unable to link each installation with a company's financial statement in the ORBIS database, and the set of variables reported in a financial statement may differ across countries. In some cases, an installation is operated by a company that is not registered in the country where the installation is located. These observations are disregarded too. Section 4 decomposes changes in emission intensity (measured in tonnes of CO_2 emitted divided by turnover) between 2013 and 2019. It therefore needs turnover to be reported in 2013 and 2019. Due to the incomplete matching between the EUTL and ORBIS and the fact that firm level variables must be observed in both 2013 and 2019, the companies included in our analysis represent 74 % of 2013 EU ETS emissions and 73 % of 2019 EU ETS emissions. This number varies between sectors and countries.

1 Combustion activities can also refer to a smaller unit that does not exceed the necessary threshold to be categorised within a specific industrial activity.

2 This includes electricity, gas, steam and air conditioning supply as well as water supply, sewerage, waste management and remediation activities.

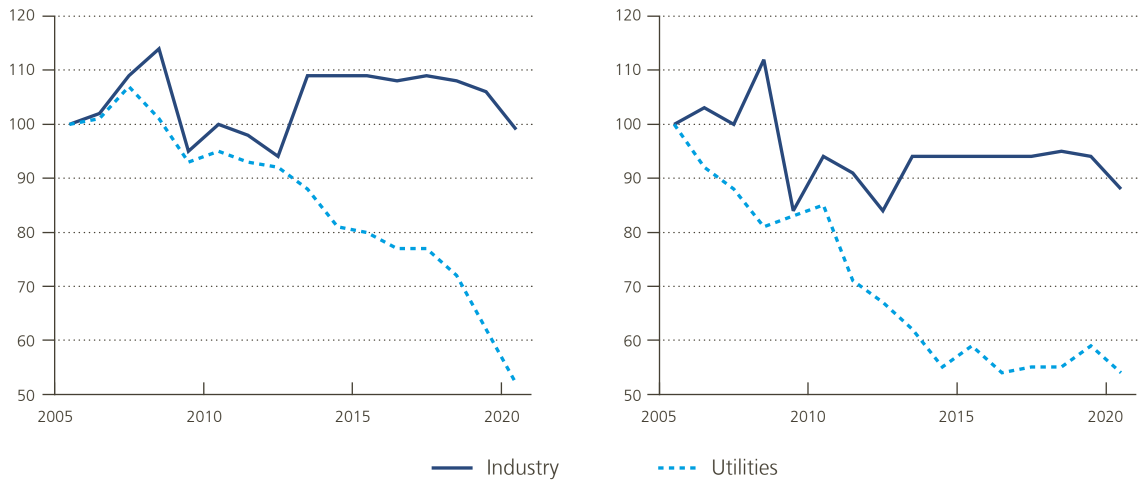
3. Emissions from EU ETS installations

EU ETS installations are classified either as utilities or as industry. Past emission reductions came predominantly from the utilities sector (chart 3). Manufacturing industry emissions have remained stable over the past decade. Belgium and the EU as a whole both display a similar trend. Emissions from the utilities sector declined significantly and halved over the period 2005-2020. However, manufacturing industry emissions remained relatively stable. Whether or not the EU ETS has been the main driver for the reduction in the utilities sector remains debatable as it is difficult to separate the effect of the ETS from other policies. Most countries introduced specific regulations and incentives independent of the ETS to support coal-to-gas switching and the uptake of RES.

Chart 3

EU-wide emission reductions come predominantly from the utilities sector. Manufacturing industry emissions have remained stable over the past decade, including in Belgium

(relative trend in emissions covered by the EU ETS for the EU as whole and for Belgium, 2005 = 100)



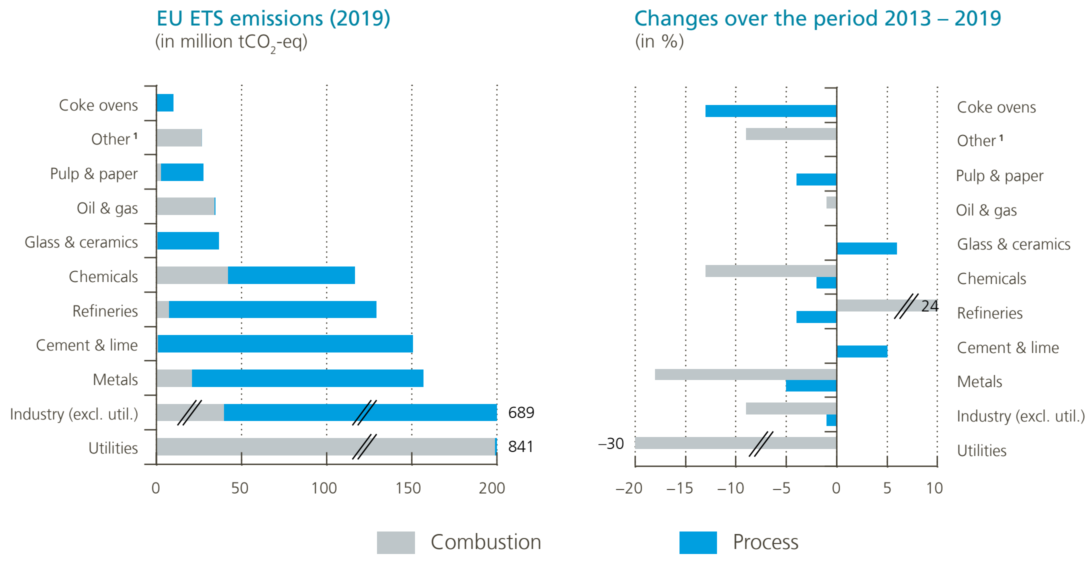
Sources: EUETS.info, NBB analysis.

The sectors or activities with the highest emissions are the utilities sector followed by metals and cement and lime (chart 4). Economic activity, however, is not the only possible dimension for analysing total emissions. A further distinction between combustion-related emissions (largely represented by electricity generation) and process-related emissions (stemming from industrial activities) is also needed for a better understanding of the remaining sticking points. Combustion-related emissions declined significantly over the period 2013-2019, [1] not only in the utilities sector but also in industry. However, process-related emissions remained stable. Technical realities may explain the slower reduction of process-related emissions compared to combustion-related emissions. The use of fossil feedstock is deeply embedded in some production processes. Examples include the use of coke for iron ore reduction in steel furnaces, and oil or natural gas as feedstock for petrochemicals and fertilisers. These industries emit CO_2 in ways additional to the generation of heat. Process-related emissions are to a certain extent directly related to the physical process itself, e.g., when limestone is turned into cement or lime. Process-related emissions therefore cannot simply be reduced by improving energy efficiency; technological change is also required. Nevertheless, Vieira *et al.* (2021) argue that the technologies to reduce these process-related emissions are already available. They believe that the reasons for the somewhat disappointing reduction in these emissions must also lie elsewhere.

1 This period is chosen because 2013 is the start of Phase 3 of the EU ETS. 2019 is preferred as a reference point as both 2020 and 2021 emissions were affected by the COVID19 crisis (See Marcu *et al.* 2022) and 2021 is the start of a new phase of the EU ETS.

Chart 4

European industry reduced its combustion-related emissions, while process-related emissions remained stable



Sources: EUETS.info, NBB analysis.
1 Other includes e.g., food processing, textiles, services.

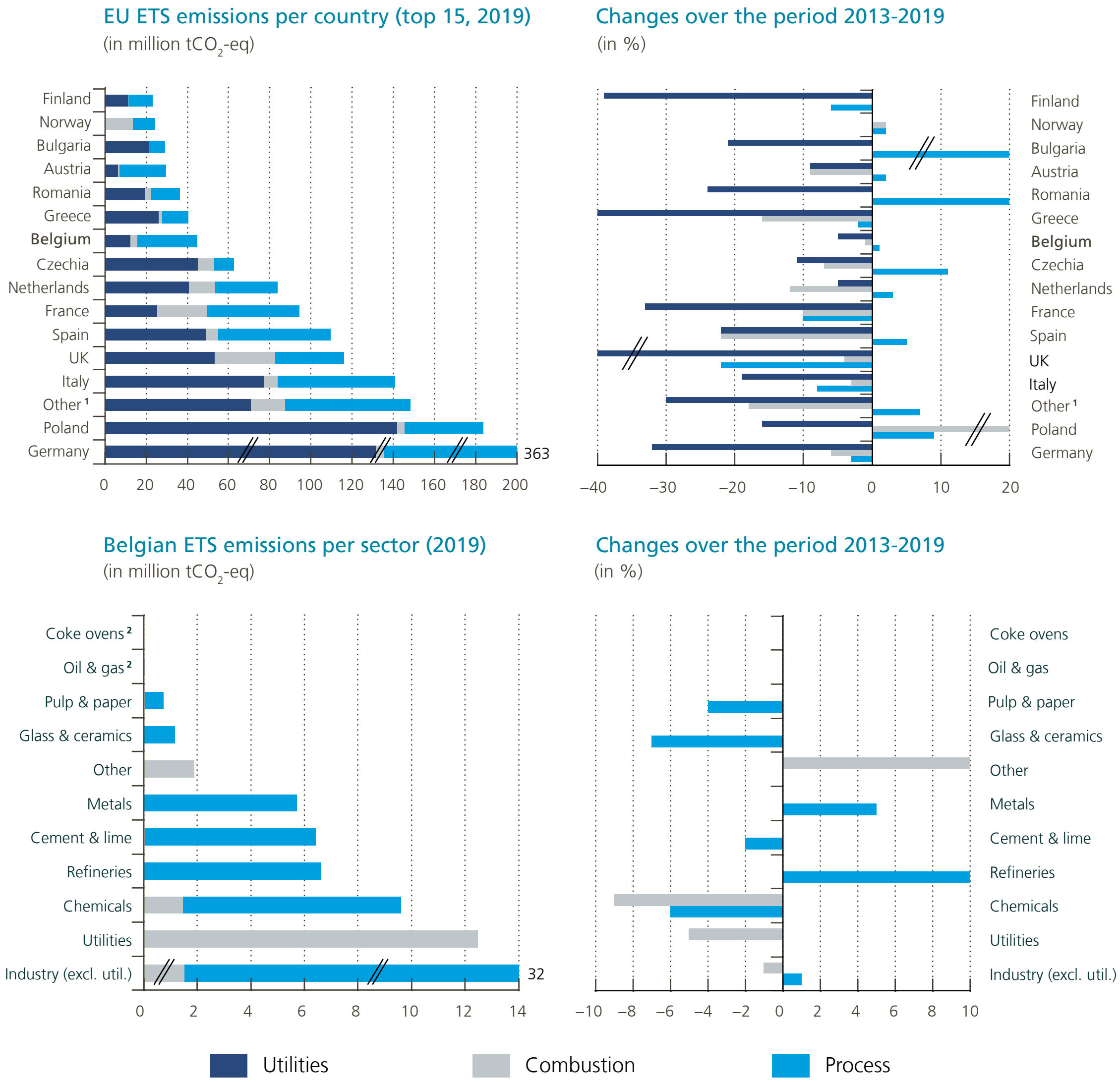
Within the EU, Germany and Poland are the biggest emitting countries (chart 5, top). Most of their emissions stem from the utilities sector, which has a relatively high GHG‑emissions intensity.[1] On the one hand this increases their overall emissions, but on the other hand it does make future emissions abatement easier. The use of renewables is a well-known way of reducing emissions in the electricity generation sector. However, Belgian emissions are predominantly driven by process-related emissions and these emissions were not reduced over the period 2013‑2019. Furthermore, as explained above, there is greater uncertainty over how these emissions can be substantially reduced in the future.

In Belgium, most of the industry's emissions are process-related and stem from chemicals, refineries, cement and lime and metals (chart 5, bottom). Refineries and metals were not able to reduce their process-related emissions over the period 2013‑2019.

1 According to the European Environment Agency, GHG emissions intensity of electricity generation in 2019 was 253 gCO_2-eq/kWh (EU27+UK), 744 (Poland), 344 (Germany), 234 (Italy), 174 (Belgium), 56 (France).

Chart 5

Nearly all countries reduced their combustion- and utilities-related emissions while process-related emissions remained at best stable.



Sources: EUETS.info, NBB analysis.
1 “Other” includes the countries not belonging to the top 15 emitters.
2 The sectors coke ovens and oil & gas are not present in Belgium.

4. The trend in emission intensity

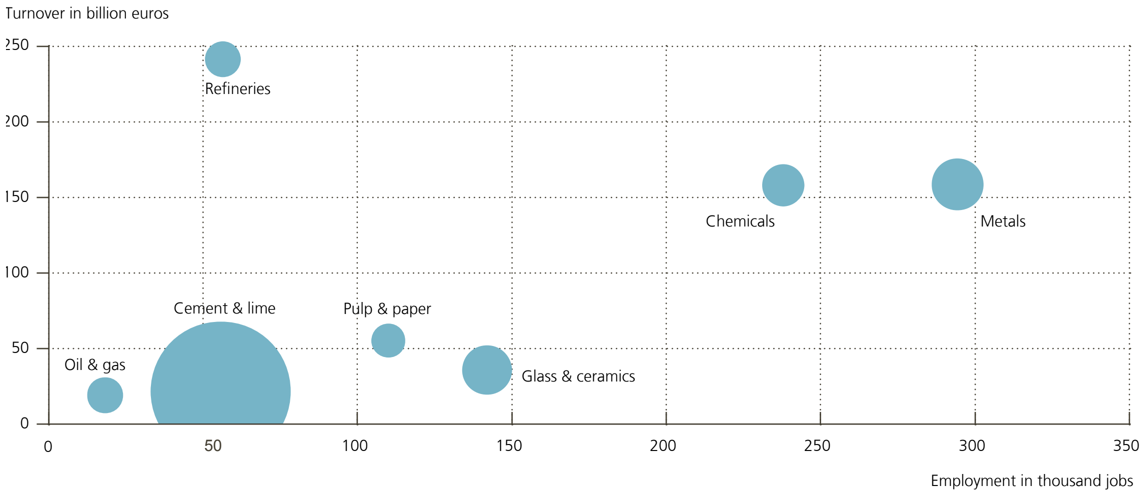
The trend in absolute emissions outlined in the previous section only tells part of the story. Emissions cannot be evaluated independently of the associated economic output. For industry, changes in emissions are closely linked with changes in output. However, declining activity is not the aim of the European Green Deal. The desired path for European industry towards climate neutrality leads via reductions in the emission-intensity of output or the amount of CO_2 emitted per unit of output. To study emission intensity, we link each emitting installation with its corporate owner as described in Section 2 and use the owner’s turnover or employment figures as a measure of output.

As chart 6 clearly illustrates, output differs substantially between sectors. Measuring output via employment or turnover does not alter this finding, as turnover and employment[1] are generally closely related for most industries except for refineries. Chemicals and metals are large sectors measured by both turnover and employment, whilst the refineries sector is very large measured by turnover and relatively small when measured by employment. Relating turnover to emissions reveals that emission intensity differs substantially between sectors. Cement & lime, a small sector, has by far the highest emission intensity.

Chart 6

Output and emission intensity, or emissions relative to output, differ substantially between sectors

(EU ETS turnover, employment and emission intensity per sector[1], 2019)



Sources: EUETS.info, ORBIS, NBB analysis.

1 Bubble size represents emission intensity based on turnover.

Over the period 2013-2019, overall emission intensity remained stable (chart 7), with a 2 % increase if the intensity is measured as emissions relative to employment and a 1 % increase if measured relative to turnover. The oil and gas sector is somewhat of an outlier as its emission intensity increased substantially.[2] We therefore also analyse the trend in intensity excluding the oil and gas sector. This reveals a comparable picture. The overall trend in emission intensity does hide considerable underlying heterogeneity between sectors. Chemicals, glass and ceramics, metals and pulp and paper substantially reduced their emissions relative to output, while the intensity of cement and lime and refineries increased, both measured relative to turnover and employment.

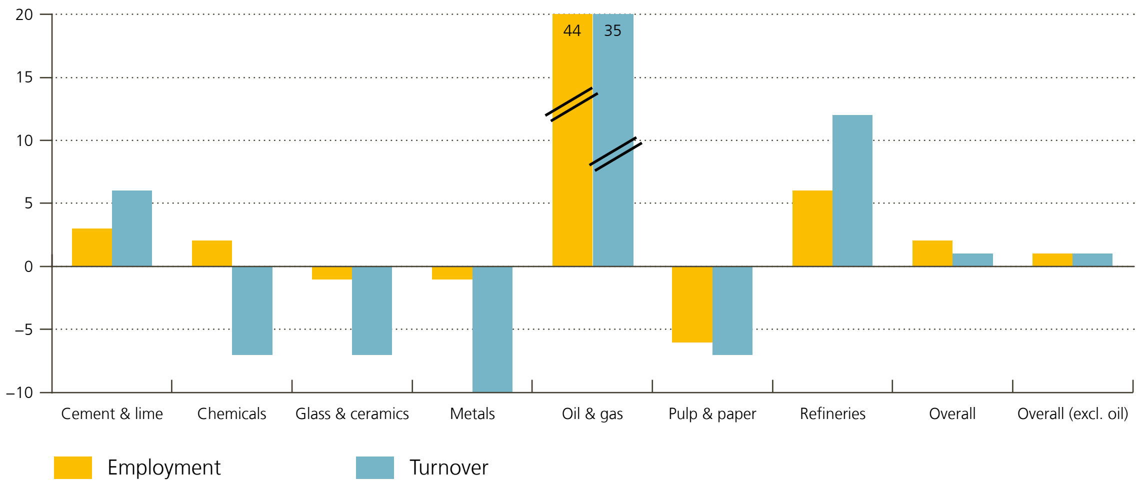
1 Turnover and employment refer to the sum of turnover and employment as reported in ORBIS for the installations that could be linked to their corporate owner. Only emissions of installations for which turnover is available are used to calculate emission intensity.

2 Note that whilst the turnover used to measure emission intensity is deflated using industry specific deflators, the volatility of oil prices potentially introduces measurement errors for the oil and gas industry. Nevertheless, the intensity of the oil and gas sector measured relative to employment also increases significantly.

Chart 7

Industry's emission intensity did not improve

(change in emission intensity[1] between 2013-2019 in percentage)



Sources: EUETS.info, ORBIS, NBB analysis.

1 Turnover is deflated based on Eurostat's national account aggregates (nama_10_a64). We use the country and A64 sector specific deflator for output (P1).

5. Reducing emissions via reallocation

To better understand the underlying processes that drive the changes in emission intensity, we use a well-known technique from the productivity literature. More specifically, we decompose the change in emission intensity to distinguish between the contributions from EU ETS firms continuing, entering, and exiting firms. The decomposition technique sheds light on the relative importance of underlying processes of innovation, reallocation, and creative destruction.

Foster *et al.* (2001) put forward a decomposition of productivity growth which we use to break down the change in emission intensity:

$$\begin{aligned}\Delta Intensity_t = & \sum_{i \in C} Share_{i,t-1}\,\Delta Intensity_{it} \\ & + \sum_{i \in C} (Intensity_{i,t-1} - \overline{Intensity}_{t-1})\Delta Share_{i,t-1} \\ & + \sum_{i \in C} \Delta Intensity_{t-1} \Delta Share_{it} \\ & + \sum_{i \in N} Share_{it}\,(Intensity_{it} - \overline{Intensity}_{t-1}) \\ & - \sum_{i \in X} Share_{i,t-1}\,(Intensity_{i,t-1} - \overline{Intensity}_{t-1})\end{aligned}$$

where $\Delta Intensity_t$ corresponds to the share-weighted growth of emission intensity, for the period ending at time t. EU ETS firms are indexed by i and may be classified as either continuing (C), entering (N), or exiting (X). $Share$ denotes the activity shares attributed to ETS firm i. Bars over variables indicate that the average has been taken over all firms. Emission intensity is measured in terms of turnover, i.e. in tonnes of CO_2 emitted per unit of turnover.

The right-hand side of the equation breaks down the change in emission intensity ($\Delta Intensity_t$) into five terms, which (respectively) correspond to the within-effect or innovation, the between-effect or reallocation, the covariance term, the contribution of entry, and the contribution of exit.

The contribution of continuing firms can be broken down into within-effects (innovation), between-effects (reallocation) and a covariance term. Within-effects correspond to changes in emission intensity within a firm, holding constant its market share. Within-effects therefore correspond to reductions in emission intensity (i.e. producing the same output, but with lower carbon emissions) that occur within an individual firm, due to innovation over time. This innovation can be linked to the adoption of a new technology or measures making the existing technology and/or processes more carbon efficient. Between-effects correspond to the reallocation that occurs due to changes in the market shares of the EU ETS firms. If this between-effect is negative, this means that production capacity is being reallocated from the most emission-intensive firms towards the less emission-intensive firms. In contrast, if the between-effect is positive, then the firms with the highest emission intensity are growing faster than the less carbon-intensive firms. The covariance term, or cross term, will be negative if growing firms reduce their emission intensity because of their growth (e.g., growth leads to lower emission intensity via scale effects), and positive if firms that reduce their intensity have decreasing market shares (e.g., lower emission intensity occurs via downsizing).

In addition, the decomposition allows us to quantify the contribution to emission reductions due to net entry, which corresponds to the sum of the contribution of entry and exit. Entry reduces average emission intensity if an entrant's intensity is lower than that of the average firm. Exit reduces average emission intensity if exiting firms have a higher emission intensity compared to the average firm. In this case, the exit of underperforming firms allows output to be reallocated to more carbon efficient uses.

Table 2 shows this decomposition of emission intensity for firms that are part of the EU ETS. It is based on both the decomposition of the overall emission intensity of all industrial sectors combined and the decomposition for the individual sectors. It compares the year 2013, the start of Phase 3, with 2019, the last representative

Table 2

The decomposition of the changes in emission intensity reveals that output was not shifted towards the most efficient firms. Firm growth did go hand in hand with reducing intensity

(emission intensity in tCO_2-eq per million € turnover [1] and in percentage change)

Industry	2013 emission intensity	Innovation	Reallocation	Covariance	Entry	Exit	2019 emission intensity
Cement & lime	4 952	312 +6%	108 +2%	–161 –3%	0 +0%	27 +1%	5 238 +6%
Metals	789	–31 –4%	21 +3%	–39 –5%	–3 +0%	–27 –3%	710 –10%
Glass & ceramics	702	–21 –3%	18 +3%	–41 –6%	–1 +0%	–3 +0%	655 –7%
Chemicals	509	52 10%	–60 –12%	–28 –6%	–10 –2%	8 +2%	472 –7%
Pulp & paper	333	–28 –8%	14 +4%	–11 –3%	1 +0%	1 +0%	309 –7%
Refineries	283	8 +3%	50 +18%	–25 –9%	1 +0%	0 +0%	317 +12%
Oil & gas	247	99 +40%	2 +1%	–11 –4%	–2 –1%	–1 +0%	333 +35%
Overall	601	17 +3%	30 +5%	–32 –5%	–4 –1%	–4 –1%	608 +1%

1 Turnover is deflated based on Eurostat's national account aggregates (nama_10_a64). We use the country and A64 sector specific deflator for output (P1).

year of Phase 3. Table 2 lists the emission intensity (in emissions per million € turnover) for 2013 and 2019 as well as the breakdown of this change in within-effects (innovation), between-effects (reallocation), covariance, entry and exit. A negative number or reduction in emission intensity is desirable.

Overall, emission intensity increased by 1 % from 601 tCO_2-eq per million € to 608. Within-firm changes or innovation did not decrease the overall emission intensity. For the individual sectors, the contribution of innovation is mixed. Only within the metals, glass and ceramics and the paper industry, individual firms became more carbon efficient and reduced their intensity. Reallocation did not reduce emission intensity either. Only in the chemicals industry did the most carbon efficient firms gain market share and reduce the average emission intensity. For all other sectors the most efficient firms did not gain market share. However, the covariance term is negative for all industrial sectors. This implies that there are carbon returns to scale in all sectors, and growing firms become more carbon efficient and reduce their emission intensity. Entry and exit contribute positively to carbon efficiency. Entering firms have a lower emission intensity compared to the average, and exiting firms have a higher intensity. The contribution of entry and exit remains limited as only a few firms enter or exit the EU ETS.

6. The untapped potential of reallocation

Many governments and industry associations rightly refer to the further development and adoption of new technologies for the purpose of decarbonising. The rationale is that, in many cases (e.g., hydrogen or carbon capture), the necessary decarbonisation technology is not yet available at an industrial scale and needs a wide range of (government) support to develop further. The fact that technologies which can substantially reduce emissions already exist and are currently already used is seldom mentioned. The underlying design of the EU ETS implicitly assumes wide variations in carbon efficiency between industrial installations within narrowly defined sectors. For the allocations of free emission allowances, EU ETS industrial installations are subdivided into 54 categories[1] for which an emission benchmark is developed. This benchmark is based on the average emissions of the best performing 10 % of the installations producing that product in the EU. It therefore acknowledges that a substantial proportion of installations that produce a similar product do not use the most carbon efficient technology that is already available at an industrial scale. Widespread adoption of the benchmark technology within each of these 54 categories would therefore already lead to a substantial emission reduction.

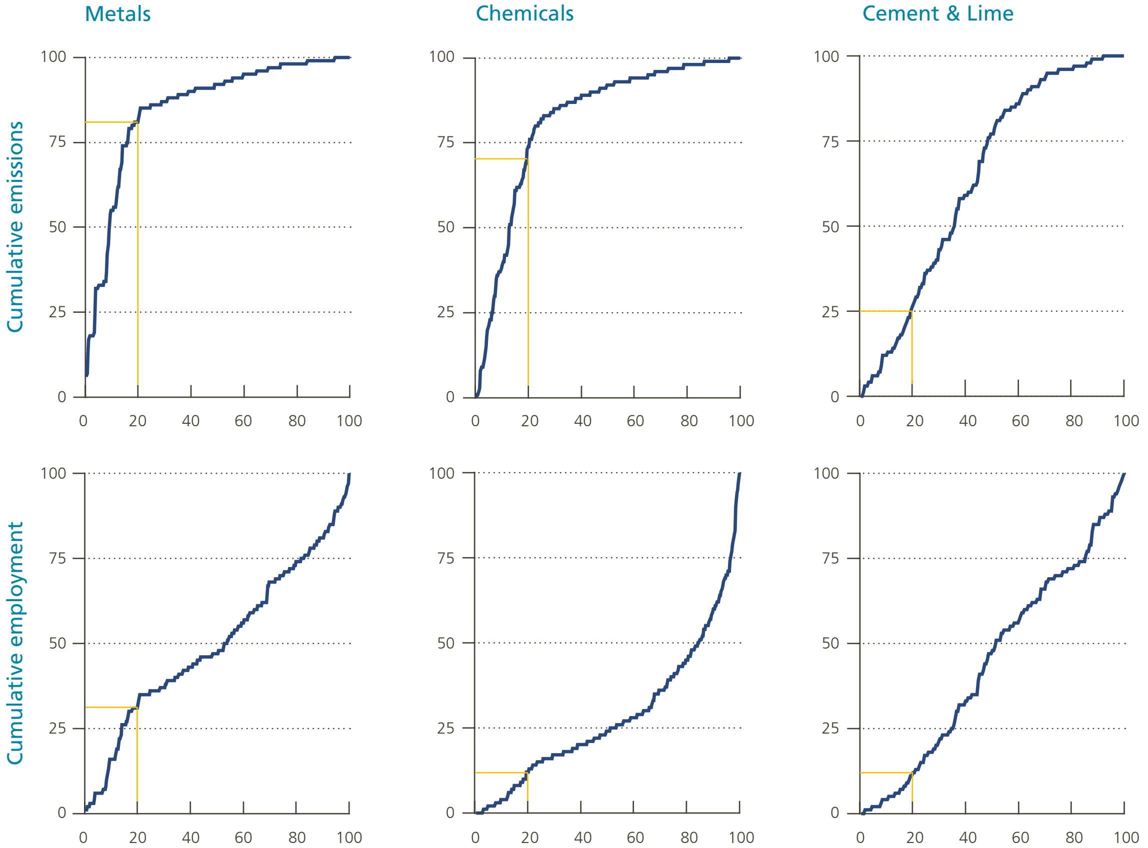
There is indeed potential for reallocation of resources between firms to lower overall emissions (chart 8). As EU ETS firms for which the necessary financial data is available cannot be meaningfully grouped into 54 sectors,[2] we cluster the industrial firms into the sectors used previously in this article. For metals and chemicals, the 20 % most emission-intensive firms represent approx. 75 % of emissions whilst they only represent 20 % to 30 % of employment. Whilst clearly some of the dispersion in carbon efficiency within the broad sectors of metals and chemicals is due to differences in the product mix of the underlying firms, it does confirm the dispersion that formed the basis for allocating free emission allowances. Even for the cement and lime sector, where there are fewer differences between the products made and the technologies used, compared to chemicals and steel, we still see some dispersion. The 20 % most emission-intensive firms represent approx. 30 % of the sector's emissions, but only 10 % of employment.

1 52 products and two so-called fallback approaches based on heat and fuel.

2 The division into 54 categories is based on installations and not on firms. Many firms operate multiple installations in different categories. There are therefore substantially fewer firms than installations in the EU ETS.

Chart 8

Emission intensity is unevenly spread across firms: a small number of firms represent a large share of emissions, but only a small share of employment[1]



Sources: EUETS.info, ORBIS, NBB analysis.

1 The horizontal axis ranks the firms from most to least emission-intensive and the vertical axis represents their cumulative emissions and employment vis-à-vis total emissions and employment. The yellow line therefore indicates the share of emissions and employment represented by the 20 % most emission-intensive firms (figures 2019).

6.1 A European reallocation scenario

A limited reallocation away from the most emission-intensive firms towards less emission-intensive firms within sectors has a significant emission saving potential. To quantify this potential, we conduct a basic thought experiment that is displayed in chart 9. We investigate what would happen if the output of the 20 % most carbon-intensive firms within an industry is redistributed over the remaining 80 % firms that are located across the countries participating in the EU ETS.[1] We make a possible reallocation or redistribution of activities more realistic and work with narrowly defined sectors. We subdivide the metals industry into basic metals, non-ferrous metals and fabricated metals. Chemicals is split into plastics and chemicals, while glass & ceramics is not taken as a whole but split into its two parts, i.e. glass and ceramics.

The 20 % most emission-intensive firms per sector are not evenly spread across Europe. In some countries only 10 % of the workforce at EU ETS firms is employed by these least carbon efficient firms, whereas in other countries this share may be up to 50 % (left-hand panel of chart 9). Our thought experiment now assumes that these firms

1 Note that this thought experience is still far less ambitious than introducing the benchmark technology for each sector.

are pushed out of the market and their output and employment are taken over by the remaining firms within their sector.[1] The share of employment at these firms gives an indication of the magnitude of the reallocation exercise where output and employment must be redistributed either within the country or between countries.

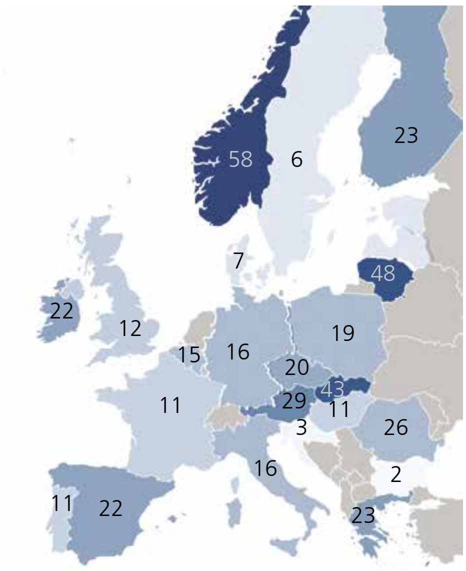
This theoretical exercise would inevitably lead to between-country flows in employment as depicted in the right-hand panel of chart 9. The output of the 20 % most carbon- intensive firms within an industry is indeed shifted towards the other 80 % within the same industry.[2] This scenario therefore assumes that total employment within a sector across the EU remains constant. Several countries such as Slovakia, Austria and Poland would lose employment at EU ETS firms owing to a shift towards countries where the 80 % most carbon-efficient firms are relatively over-represented, such as Italy, France and Sweden. The emission-saving potential of such a reallocation exercise is substantial: the reallocated output of the bottom performers would now be produced with ~80 % less emissions. Overall emissions would drop by ~40 %.

Chart 9

A limited reallocation of the 20 % most emission-intensive firms towards the 80 % least intensive firms within sectors will have a heterogenous impact on workers who need to be reallocated either within or between countries

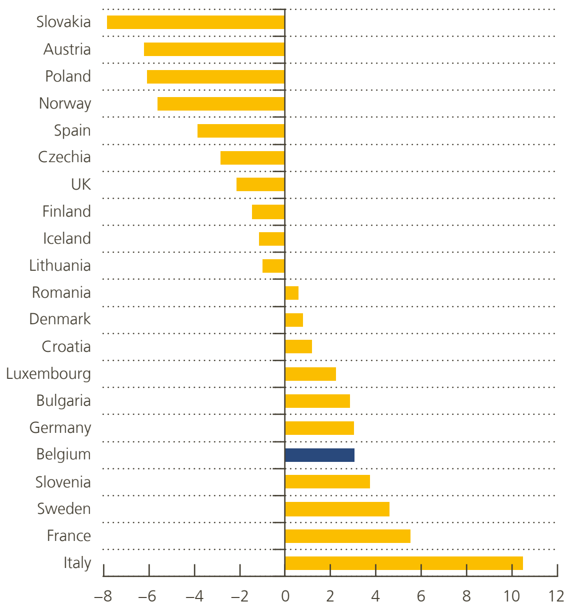
Jobs at the 20 % emission-intensive firms per sector[1]

(in % of total employment at ETS firms)



Reallocation of jobs between countries

(in thousand jobs)



Sources: EUETS.info, NBB analysis

1 Figures 2019, financial figures for Dutch ETS firms not available.

2 For clarity, countries with limited job reallocation (less than 500) are omitted.

1 This exercise does not take into account that these firms could also become more carbon efficient by adopting new technologies themselves.

2 The output is reallocated based on the employment distribution across the countries of the 80 %. I.e., if a country represents one tenth of the employment of the 80 % most carbon efficient firms, one tenth of the employment of the 20 % least efficient firms is reallocated towards that country.

6.2 A Belgian reallocation scenario

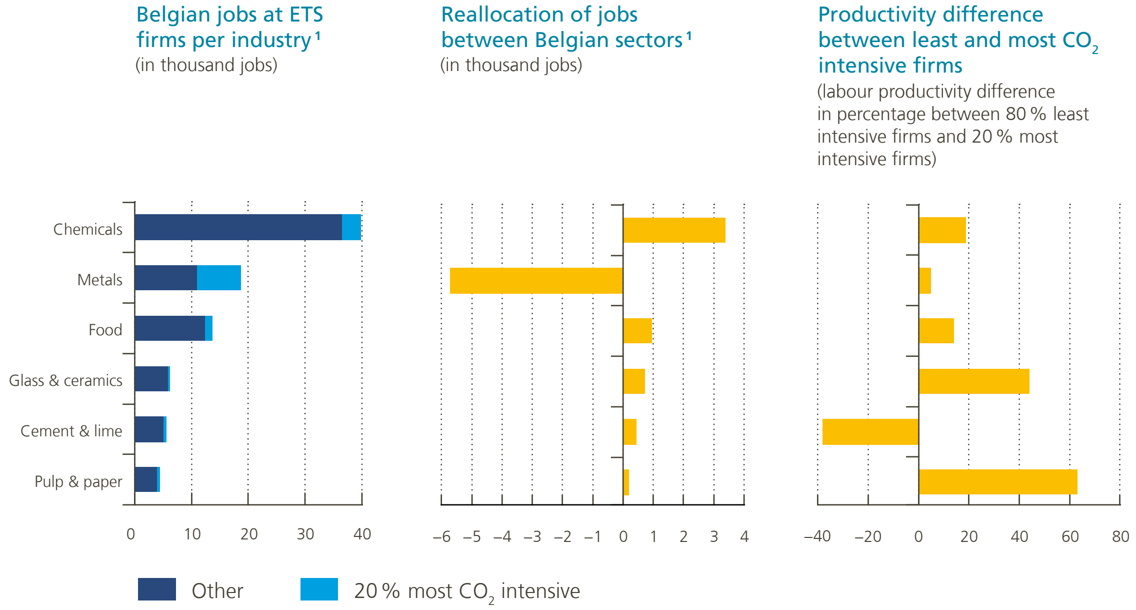
A similar exercise that focuses purely on Belgian firms within the EU ETS reduces emissions and increases productivity. We investigate the outcome of shifting the employment of the 20 % most carbon-intensive firms within each sector towards the other 80 % of firms. Since Belgium only has approx. 150 industrial firms[1] that are part of the EU ETS, we do not assume a reallocation scenario within the different sectors, but across sectors. We do not redistribute employment within sectors, but across sectors. Contrary to the European scenario in the previous section, the Belgian scenario therefore does not keep employment constant within each sector.

Chemicals, metals and food employ the most people at Belgian EU ETS firms (chart 10, left-hand panel). Cement and lime only represent a small part of employment, although this sector represents approx. 20 % of Belgian industrial emissions within the EU ETS. Employment at the 20 % most emission-intensive firms is disproportionally found within the metals sector. This reallocation scenario would therefore result in employment shifting away from the metals sector towards predominantly the chemicals industry and to a lesser extent to other industries, as illustrated in the middle panel of chart 10. The overall emission-saving potential of this exercise amounts to ~60 % of Belgian industrial EU ETS emissions. In addition (as depicted in the right-hand panel of chart 10), there are productivity differences between the most and least emission-intensive firms. For almost all sectors the 80 % least emission-intensive firms are also more productive than the 20 % most emission-intensive firms. The Belgian theoretical reallocation scenario would therefore not only reduce emissions, but also increase productivity.

1 For Belgium we have detailed firm-level financial information available via the Central Balance Sheet Office (CBSO). Consequently, for firm-level financials and employment we do not make use of ORBIS but rely on the CBSO.

Chart 10

Impact on employment and productivity of a within-Belgium scenario where the 20 % most emission-intensive firms per sector are reallocated. This results in a productivity improvement in almost all sectors



Sources: EUETS.info, Central Balance Sheet Office, NBB analysis.
1 Figures for 2019.
2 A positive number indicates that the least emission-intensive firms are more productive.

7. Carbon prices as a driver for reallocation

Of course, the reallocation scenarios described in the previous section are hypothetical. The main message is that, besides within-firm improvement and technological change, there is potential for reducing emissions by moving output to the cleanest firms within a given sector. Increasing carbon prices will not only give an incentive to the least energy efficient firms to catch up technology-wise but may also drive reallocation. Firms that have limited cashflows compared to their emissions may become unprofitable if carbon prices continue to rise and/or their free emission allowances are reduced. Having to pay a higher price for its CO_2 emissions directly reduces the firm's cashflow, if all other things remain equal.

Relating cashflows to emissions, we observe that the cashflow[1] per emitted tonne of CO_2 differs remarkably between countries (chart 11). Norway, Sweden, Belgium and the UK have cashflows of more than € 400/tCO_2 (yellow bar in chart 11). On average, firms in these countries can easily absorb rising carbon prices even without having to raise their prices. Conversely, firms in Romania, Germany and Slovakia generate cashflows below € 100/tCO_2 and have limited capacity to absorb higher carbon prices without having to raise their prices.

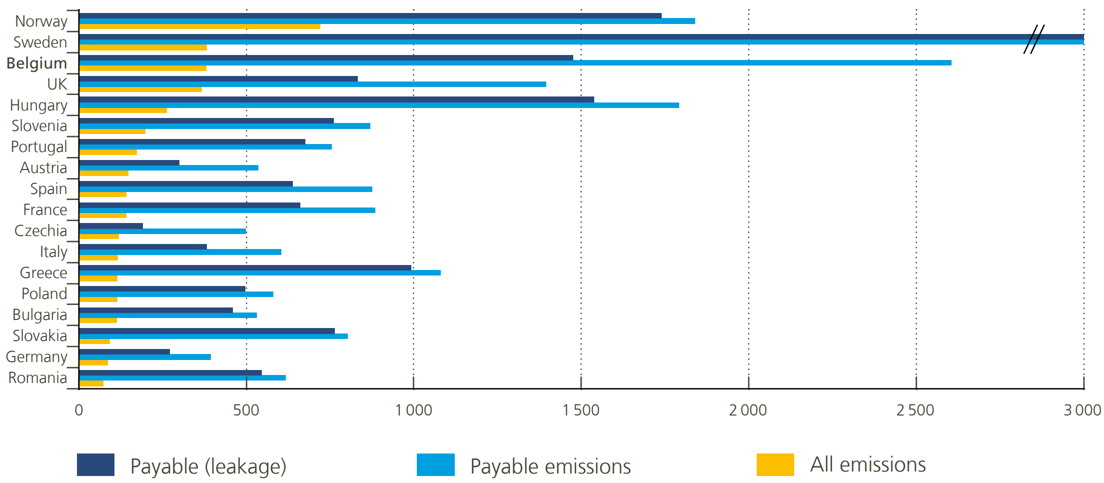
The cashflow per emitted tonne also changes depending on which emissions are considered. The yellow bar in chart 11 labelled "All emissions" shows the total cashflow divided by the total of verified emissions stemming from these firms. As described in Section 1, industrial firms receive a substantial part of their emission allocations for free. This free allocation is not impacted if carbon prices increase. Therefore, the light blue bar, labelled "Payable emissions", only considers the emissions that actually have to be paid. The cashflow per tonne of CO_2 now rises substantially, and is well above € 500/tCO_2 in all countries except Germany.

1 Cashflow is measured via Earnings Before Interest, Taxes, Depreciation and Amortisation (EBITDA) reported in ORBIS.

Chart 11

The cashflow generated per emitted tonne differs substantially between countries, and changes when we take into account free emission rights and the leakage list

(EBITDA[1] per emission in €/tCO_2 for EU ETS firms[2], industrial firms only, figures for 2019)



Sources: EUETS.info, ORBIS, NBB analysis.
1 EBITDA stands for Earnings Before Interest, Taxes, Depreciation and Amortisation.
2 Average per country calculated as total EBITDA divided by total emissions of firms for which EBITDA is available.

However, these free emission allowances are to be gradually phased out. By 2030[1] firms within the EU ETS will effectively have to pay for all their CO_2 emissions, although there are some exceptions. If the firm's activity is on the so-called leakage list, the installation will continue to receive free emission allowances. Therefore, the dark blue bar in chart 11, labelled "Payable (leakage)", does not consider free emission allowances unless the firm's activity is on this leakage list. This reduces the cashflow per tonne of CO_2 compared to the light blue bar that reflects the situation where the free allowances are fully considered. Taking into account this leakages list, we observe that – apart from firms in Czechia, Germany and Austria – firms in most countries, on average, generate a cashflow per emitted tonne well above € 300.

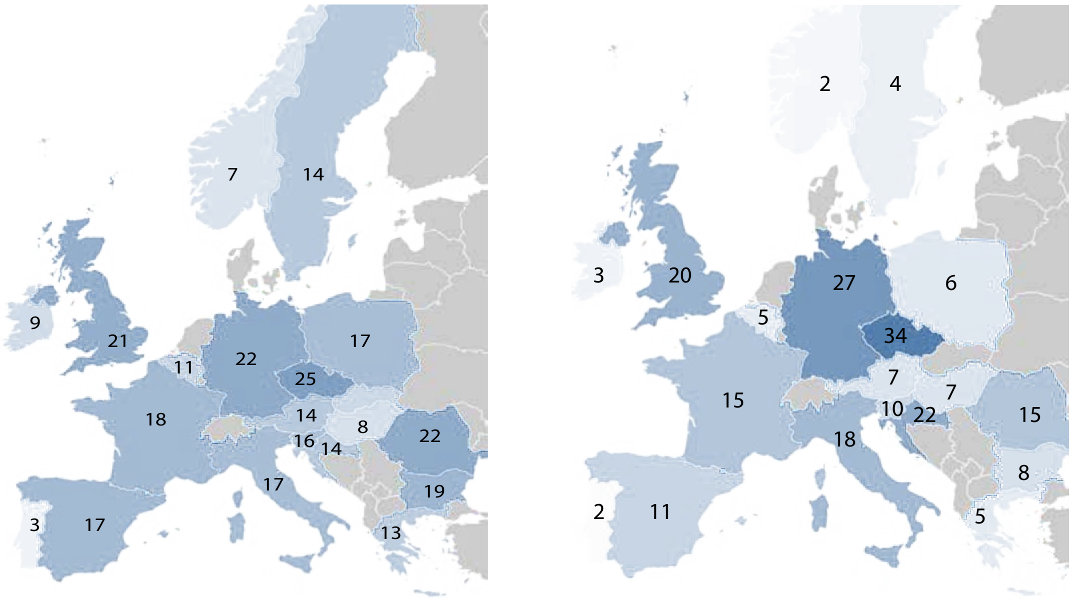
Chart 12

Carbon prices can drive reallocation as an increased carbon price may put many firms at risk of a negative cashflow

(share of ETS firms and employment that become cashflow negative in a cashflow-driven scenario[1], figures 2019, in percentage)

Share of industrial *firms* at risk with ETS price at €150/tCO_2
(in %)

Share of industrial *employment* at risk with ETS price at €150/tCO_2
(in %)



Sources: EUETS.info, ORBIS, NBB analysis.

1 Share of firms with an EBITDA (2019) below € 130/tCO_2. Free allowances are only taken into account if the firm's activity is on the leakage list, i.e. "Payable (leakage)" of chart 12.

The above findings for cashflows vs. emissions are based on averages. The use of averages does not consider the underlying heterogeneity of the generated cashflow per emitted tonne of CO_2. Whilst, on average, firms might well be able to absorb increasing carbon prices, some less profitable firms might not. We therefore also investigate the impact of increasing carbon prices on the least profitable firms. We start from a scenario where the carbon price increases to € 150/tCO_2. Since the carbon price was effectively € 130 lower throughout 2019 (or approx. € 20/tCO_2) compared to this € 150/tCO_2, a firm that had a cashflow below € 130 per emitted tonne in 2019 would become unprofitable, keeping all other things equal.[2] As graphically outlined in the left-hand panel of chart 12,

1 Or 2032. Note that the final mechanism and date on how free allowances will expire is still being debated.

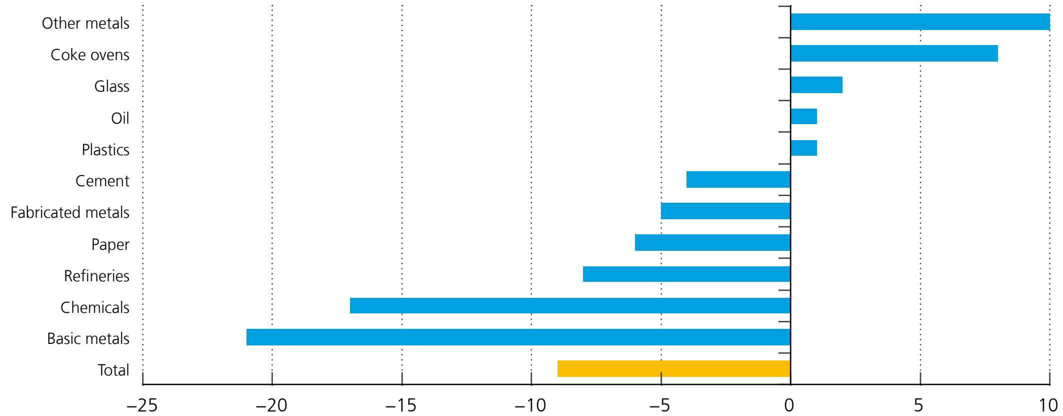
2 For the sake of simplicity, this scenario does not assume any pass-through of carbon prices into sales prices, nor any reduction of emissions driven by an increasing carbon price, nor any change in the sold volumes. Hintermann *et al.* (2020) find that firms pass on shocks to materials costs completely, or even more than completely, whereas pass-through of energy costs is around 35-60 %.

the share of EU ETS firms per country that would become unprofitable in this scenario differs substantially between countries. For instance, in Czechia, 25 % of firms could become unprofitable, whereas in Belgium this would only be 11 % of firms. The share of employment that these "at risk" firms represent is generally lower than the share of firms at risk (chart 12, right-hand panel). This indicates that, for most countries, the firms at risk of becoming cashflow negative generally employ less than the average number of workers per EU ETS firm.

Chart 13

A reallocation scenario away from firms with low cashflow does not necessarily lead to large emission savings

(emissions saved in percentage of sectoral emissions based on a cashflow-driven reallocation scenario, figures 2019)



Sources: EUETS.info, ORBIS, NBB analysis.

However, a reallocation driven by firms that become cashflow negative owing to an increasing carbon price is not necessarily the optimal reallocation to reduce emissions (chart 13). The scenario described above, based on a € 150/tCO_2 carbon price, would reduce overall emissions just below 10 %, although the effect differs substantially between sectors. The basic metals industry would reduce its emissions by 20 %, but other sectors such as other metals and coke ovens would see an increase in their emissions. This means that firms with the lowest cashflows per emitted tonne are not necessarily the ones with the highest carbon intensity.[1]

Conclusion

Based on the CO_2 emissions data from the EU ETS, we find that, unlike the electricity sector, manufacturing industry have not yet significantly reduced their emissions over the past decade. Nevertheless, the EU's "Fit for 55" package of measures contains ambitious targets for reducing CO_2 emissions by 2030. Future emission reductions will therefore not only have to rely on innovation, but also on technological "catching-up" and the reallocation of economic activity to the most CO_2-efficient companies. A limited shift of activities within a sector away from those companies that produce the most emissions, could lead to substantial emission reductions. A rising CO_2 price would not only stimulate innovation but would also encourage this reallocation, as some industrial firms might become loss-making at higher CO_2 prices.

1 As stated earlier, this scenario does not consider any cost pass-through. Cost pass-through could well be an additional source of suboptimal reallocation where the ability to pass-through carbon costs rather than carbon intensity drive reallocation. De Beule *et al.* (2022) find that sectors with low carbon cost pass-through appear more likely to relocate their activities.

Since its introduction in 2005, the EU ETS has been an ambitious attempt to reconcile economic growth with the reduction of carbon emissions from large companies in both the manufacturing and energy sectors. The ETS operates as a "cap and trade" system whereby installations can use CO_2 emissions trading to offset emissions above or below a certain threshold of freely allocated allowances. The third phase of the ETS ended in 2020 and had the goal of reducing emissions across the EU by 21 % (compared to 2005). Actual emissions remained far below the set cap. For the next phase (until 2030), the emissions cap will be further reduced to 43 % (compared to 2005). This target might be further tightened in accordance with the "Fit for 55" package of measures proposed by the EC in 2021.

Analysing the EU ETS emissions in detail, we observe that the overall emission reductions were predominantly driven by the power generation sector. The use of RES has indeed increased substantially, and the use of coal for electricity generation is gradually being phased out. Manufacturing industry, however, has not substantially reduced its emissions over the past decade, both EU-wide and in Belgium. A possible reason is that, whilst the future path for electricity generation is fairly clear, for the manufacturing sector there is uncertainty on what technologies should be adopted and what their actual potential is for carbon abatement.

The overall reductions in ETS sectors' emissions during the past decade could well have been the easy wins. Over the next decade, if the ambitious "Fit for 55" target is to be achieved, not only will the energy sector need to further decarbonise, but manufacturing industry will also need to start its deep decarbonisation. To reduce emissions, firms can either strive to become more carbon efficient, or the worst performing firms can shrink and leave the market to more efficient ones. These concepts of innovation vs. reallocation are well known for their contribution to overall productivity growth. However, the debate around decarbonisation of the economy has predominantly focused on adopting new technologies rather than also fully exploiting the potential of current technology.

We also analyse the underlying drivers of changes in emission intensity in manufacturing industry and find that, in the past, production has not shifted to the most carbon efficient firms. The contribution of innovation was mixed. It was positive for e.g., the chemicals industry, but negative for the metals industry. Firm growth, however, did go hand in hand with reducing carbon intensity.

Regarding the redistribution of activities or reallocation, we find that emission intensity is very unevenly distributed among firms within the same manufacturing sector. For most sectors, a limited number of firms with relatively poor emission efficiency account for a large share of emissions. This implies that there is a huge untapped potential for technological "catching-up" and reallocation of activities between firms to reduce overall emissions. A limited reallocation away from the most emission-intensive firms could result in an overall emission reduction of ~40 %. A rising carbon price could drive this reallocation process, as it puts some firms at risk of negative cashflow. However, this carbon price-driven redistribution will not necessarily be the optimal redistribution to reduce emissions. This is because the least profitable firms are not always the least carbon efficient. This means that a broader mix of policy measures will be needed to decarbonise the manufacturing sector in a timely manner. Carbon pricing could therefore be accompanied by carbon efficiency targets to ensure that highly profitable sectors or firms with low carbon efficiency also see an incentive to green their activities, and production is reallocated to the least emitting firms.

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Conventional signs

€	euro
%	per cent
e.g.	*exempli gratia* (for example)
et al.	*et alia* (and others)
i.e.	*id est* (that is)

List of abbreviations

Countries or regions

EU	European Union
EU27	European Union of 27 countries
EU28	European Union of 28 countries (still incl. UK)
UK	United Kingdom
US	United States

Abbreviations

CBAM	Carbon Border Adjustment Mechanism
CBSO	Central Balance Sheet Office
COVID-19	Coronavirus disease-19
CO_2	Carbon dioxide
EBITDA	Earnings before interest, taxes, depreciation and amortisation
EC	European Commission
EEA	European Environmental Agency
EEX	European Energy Exchange
ESR	Effort Sharing Regulation
EUA	European Union Emission Allowance
EUAA	European Union Aviation Allowance
EU ETS	European Union Emissions Trading System
EUTL	European Union Transaction Log
GHG	Greenhouse gas
kWh	Kilowatt-hour
LRF	Linear reduction factor
LSEG	London Stock Exchange Group
LULUCF	Land use, land use change and forestry
MSR	Market Stability Reserve
MW	Megawatt
NACE	Nomenclature of economic activities of the European Community
NBB	National Bank of Belgium

N_2O	Nitrous oxide
PFC	Perfluorocarbons
RES	Renewable energy sources

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