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Hunting "brown zombies" to reduce industry's carbon footprint

by Gert Bijnens and Carine Swartenbroekx

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Abstract

This paper provides a first estimate of the potential greenhouse gas mitigation from the intra-sector reallocation of economic activity by the European manufacturing industry away from carbon-inefficient – or "brown zombie" – firms to more carbon-efficient firms. Using techniques from the literature on productivity, we find a potential reduction of 38% based on a limited reallocation of production, without the need for new technologies. Therefore, when designing emission reduction plans, policymakers should not focus solely on improvements and innovation within existing firms but must also encourage the reallocation of economic activity from "brown zombies" to more carbon-efficient enterprises.

Keywords: climate policy, carbon emission reduction, carbon-intensive industries, reallocation, brown zombies

JEL Codes: D22, L23, L52, L60, O14, Q58.

Authors:
Gert Bijnens, National Bank of Belgium, Research Department, and KU Leuven, Department of Economics.
E-mail: Gert.Bijnens@nbb.be
Carine Swartenbroekx, National Bank of Belgium, Economics and Research Department
E-mail: Carine.Swartenbroekx@nbb.be

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Non-technical summary

The European Union's ambitious "Fit for 55" initiative, part of the broader "Green Deal" program, aims to slash greenhouse gas emissions by 55 % by 2030 compared to 1990 levels. While the EU's current strategy heavily emphasizes developing new green technologies, we propose an additional approach to achieving significant emission reductions: reallocating resources from less efficient to more efficient firms within the same industry.

This concept draws parallels with how productivity improvements often stem from shifting resources to more productive companies. We introduce the term "brown zombies" to describe the least carbon-efficient firms within a sector. Although we do not question the importance of green innovation, we argue that by redirecting production from these inefficient entities to more carbon-efficient counterparts, substantial emission reductions could be achieved without relying solely on new technologies.

Analysis of data from 2013 to 2019 reveals that the manufacturing industry showed minimal improvement in emission intensity during this period. However, we observe considerable variation in carbon efficiency among firms within the same sector, indicating that some companies are already employing more carbon-efficient practices or technologies than their industry peers. To illustrate the potential impact of resource reallocation, we conduct a thought experiment. We redistribute the output of the 20 % least efficient firms (the "brown zombies") to the 80 % more efficient firms within each sector. This hypothetical scenario estimated a potential emission reduction of up to 38 % across the EU, while only affecting about 7% of total industrial output.

Meeting the EU's ambitious 2030 targets will require both technological innovation and resource reallocation. Policymakers are urged to consider not only how to make existing firms greener but also how to encourage the growth of more carbon-efficient companies at the expense of less efficient ones. While developing new green technologies remains crucial for long-term climate neutrality, reallocating production from "brown zombies" to more efficient firms could provide a faster path to significant emission reductions in the short to medium term. This dual approach, combining resource reallocation with ongoing innovation efforts, could help the EU manufacturing sector make substantial progress towards its ambitious climate goals.

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1. Introduction

The European Union's (EU) "Fit for 55" package of measures, a part of the "Green Deal" initiative,[1] contains ambitious targets for cutting greenhouse gas (GHG) emissions by 55% by 2030, compared to 1990 levels. If this reduction is not to go hand in hand with a substantial scaling down of industrial output, it implies that the carbon efficiency of European industry will have to improve drastically. Industry will have to produce the same (or higher) output with lower GHG emissions.

The debate over how to realise this ambition predominantly focuses on green innovation. The European Commission (EC) intends the new EU Industrial Strategy to lead the region's manufacturing firms towards 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"*.[2] The focus is clearly on developing innovative technology and processes and ensuring their adoption across Europe.[3] Although we do not question 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 EU policy instrument that regulates industry emissions is the European Union Emissions Trading System (EU ETS).[4] This system forces large industrial installations to pay for at least a part of their CO_2 emissions. It not only provides a financial incentive for the adoption of renewable energy sources but also stimulates the emission-intensive manufacturing sector to reduce its carbon footprint. A complex system is used to distribute free emission rights amongst industrial installations, which is based on a benchmark set by the best-performing installations producing a similar product. This system hence acknowledges that there is a certain range of carbon performance within narrowly defined sectors. More specifically, Vieira *et al*. (2021) studied the progress of EU ETS emissions and found that manufacturing firms carrying out the same activities presented results ranging from no reduction to an abatement of more than 80% of emissions over the period 2005–2017. They therefore concluded that a lack of alternative technologies could not be the sole reason for poor mitigation results. More recently, Capelle *et al*. (2023) analysed self-reported emission data for a global sample of 4 000 large, publicly listed companies and found significant heterogeneity in environmental performance within the same industry and country.

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[1] The European Green Deal is a set of policy initiatives launched by the European Commission (EC) with the aim of making Europe the first climate-neutral region in the world.

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

[3] The recent Pisani-Ferry and Mahfouz (2023) report for France is somewhat more nuanced and states that a revolution is needed not only in production methods but also in consumption patterns. The latter also implies a reallocation of economic output between production sectors. Nevertheless, the projections of the cost of the transition for industry are based on greening existing high carbon-emitting production sites.

[4] More information on the EU ETS can be found in Bijnens and Swartenbroekx (2022).

In this paper, we therefore propose another way of improving the aggregate carbon efficiency of the manufacturing sector, in addition to pursuing innovation and other improvements within existing firms. This involves the reallocation or shift of resources between firms and industries away from carbon-inefficient companies towards more carbon-efficient ones. The importance of reallocation for aggregate productivity gains has been well established since the seminal work of Foster *et al.* (2001). They found that this mechanism of reallocating economic activity towards the most productive firms accounts for around 50 % of productivity growth in US manufacturing and 90 % in the retail sector. Other authors have found comparable results for Europe.[5] When resources are shifted from low- to high-productivity firms, aggregate productivity rises without an increase in the underlying productivity of individual firms.

We apply similar reasoning to gains in carbon efficiency, which we think of as "carbon productivity" or how effective companies utilise carbon emissions to produce a given level of output.[6] Existing firms can innovate, change their production techniques or invest in abatement to reduce their carbon emissions. These are the so called within firm improvements. In addition, they can reallocate resources. Reallocation refers to resources that are redistributed, within or between carbon-intensive industries, toward relatively more carbon-efficient firms, through the downsizing of the most carbon-intensive incumbents and the growth of cleaner enterprises. The concept of "zombie" firms – defined as low-productivity firms that would typically exit a competitive market – is well known in the productivity literature.[7] Due to their increasing survival rates over the past decade, they tie up scarce capital and therefore constrain the growth of more productive firms. In other words, zombie firms impede reallocation that could increase productivity. We in turn introduce here the concept of "brown zombies", or firms with the lowest "carbon productivity" within their sector.

Our analysis reveals that manufacturing industry has demonstrated negligible reductions in emission intensity over the 2013–2019 period. Even within finely defined sectors, there exists a substantial variability in emission intensity, defined as the ratio of emissions to value added. While there was a marginal decrease in emission intensity between 2013 and 2019, primarily attributed to resource reallocation, noteworthy reductions were not driven by within firm improvements, nor by firms entering or exiting the market. To reach the targets set, future emission reductions must markedly surpass historical achievements. Beyond technological advancements, there remains considerable potential for emission mitigation by transitioning production to the most carbon-efficient entities within a sector, thereby moving output away from "brown zombies".

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[5] E.g. Gamberoni *et al.* (2016) for the Eurozone, Ben Hassine (2019) for France.

[6] The concept of carbon productivity was firstly proposed by Kaya & Yokobori (1997) and used to describe aggregate carbon efficiency defined as GDP produced per unit of carbon emission (or vice versa).

[7] See e.g. Adalet McGowan *et al.* (2018). Zombie firms are non-viable firms that may be increasingly kept alive by the legacy of the financial crisis, with bank forbearance, prolonged monetary stimulus, and the persistence of crisis-induced SME support policy initiatives.

As a first contribution, we introduce decomposition methods from the productivity literature to analyse past changes in carbon emission intensity. As a second contribution, we are amongst the first to estimate the mitigation potential due to intra-sector reallocation of economic activity away from carbon-inefficient firms towards carbon-productive ones.[8] We find that a limited shift within a sector and away from the most emission-intensive firms could result in a 38% reduction in emissions across the EU. Therefore, when developing emission reduction plans, policy makers should not focus solely on greening incumbent industrial firms but must consider that some brown zombies will have to shrink and cede the market to more carbon-efficient companies.

This paper is organised as follows: the next section summarises the data we use. Section 3 breaks down past changes in emission intensity into contributions from within firm improvements, reallocation, and market entry and exit. Section 4 quantifies the potential for future emission reductions from reallocation. Section 5 presents our conclusions and highlights the need to consider the reallocation of industrial activity to meet the EU's emission reduction targets.

2. Data

2.1 GHG emissions and emission intensity at the firm-level

The analysis in this paper is based on linking installation-level GHG emission data from the EU ETS with firm-level financial data from Bureau Van Dijk’s ORBIS database. This allows us to track firm-level emission intensity, i.e. emissions relative to output. Below we further describe each data source in detail and provide summary statistics.

We start from the European Union Transaction Log (EUTL), the central reporting and monitoring system for all EU ETS transactions managed by the European Commission. The system covers some 10 000 stationary installations in the energy and industry sectors and airlines operating in the EU. All industrial installations above a certain thermal input capacity threshold are regulated by the EU ETS. Each installation must report annually on the verified amount of CO_2 emitted.[9] For each tonne emitted, the company owning the installation must surrender a right to emit (an emission allowance) to the European Commission. Companies regulated by the EU ETS must acquire these allowances either on the carbon market or through EU ETS auctions. Many manufacturing firms regulated by the EU ETS receive a significant number of allowances for free.

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[8] Capelle *et al.* (2023) use information on 4 000 publicly listed firms across the world and estimate that if all these firms were to produce at the emission intensity of the 25th percentile within their country and industry, aggregate emissions would fall by 33 %. Note that since the EU ETS is valid for the entire EU, in this paper we do not compare emission intensities within a country, but within the EU.

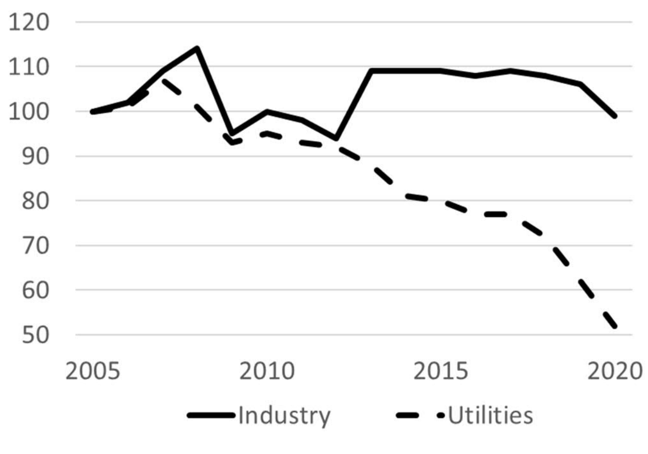
[9] The emission unit used within the EU ETS is CO_2-eq. or CO_2-equivalent as the system also covers GHGs other than CO_2.

The boundary of the emissions regulated by the EU ETS is the installation itself. The EU ETS requires the owner of an installation to hand over emission allowances for the direct emissions of that installation (scope 1). Emissions from the suppliers to the installation (either emissions from electricity consumption, scope 2, or other externally purchased products, scope 3) are therefore only covered by the EU ETS, if the supplying installation is covered by the EU ETS. If an installation or firm has its own electricity generation unit, the firm also needs to surrender allowances for the emissions of its own, in-house electricity generation unit. In short, an owner of an installation regulated by the EU ETS only needs emission allowances for the emissions directly originating from that installation.

The European Union Transaction Log (EUTL) includes 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 provides a national company registration number and company name that links the installation to its corporate operator. The EUTL also includes an activity for each installation. The list of activities can be found in the Appendix. Each activity is either linked to a product (e.g. "processing of ferrous metals", "production of ammonia") or to "combustion". A combustion installation generally refers to an installation that uses heat to generate electricity and, consequently, companies in the utilities or power generation sector operate most of them. A combustion installation may also belong to a manufacturing company whose activity is not specifically included in the EU ETS (e.g. food processing) or a services company or organisation (e.g. hospitals, universities).

EU ETS emissions from installations operated by a utility company declined significantly and halved over the 2005–2020 period (figure I). Power companies reduced carbon intensity through measures such as coal-to-gas switching and increased adoption of renewable energy sources (Marcu *et al.*, 2021). However, emissions from installations outside the utilities industry remained stable over the past decade.

Figure I - Relative trend in emissions covered by the EU ETS, 2005 = 100



Note: "Utilities" include emissions from all installations for which the operator has a NACE code between 35 and 39. "Industry" includes emissions from all other stationary installations.
Source: EUTL.

This trend in absolute emissions 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 toward climate neutrality for European industry leads from reductions in the emission-intensity of outputs or in the amount of CO_2 emitted per unit of output.

We use value added as a measure for firm output. To link emissions with value added, we use information on the corporate operator or owner of the installation gathered from Bureau van Dijk's ORBIS database. ORBIS is the largest cross-country, firm-level database available and accessible for economic and financial research.[10] It is a commercial database provided by the electronic publishing firm Bureau Van Dijk. ORBIS collects information from administrative sources, in particular, detailed balance sheets, income statements, and the profit and loss accounts of firms. The financial accounting data is harmonised across countries and provided in a standard global format. We use unconsolidated financial information from local registry filings to ensure that only financial information from activities carried out by the specific entity are included in our analysis, as opposed to consolidated accounts that may include the activities of other companies from the same group. Our analysis makes use of the ORBIS value added (in euro[11]) and industry (2-digit NACE code) variables. When value added is not reported we take the difference between operating revenue and intermediate inputs. Value added is deflated with a corresponding deflator specific for value added at the two-digit industry-country level. The deflators are retrieved from the Structural Analysis Database of the OECD.[12] In case 2-digit deflators are not available, we use the information from higher levels of industry aggregation. Since year-on-year changes in value added can be volatile, the growth rate is winsorised at the 1st and 99th percentile.

We link the installation from the EUTL with its corporate owner in ORBIS. Where a direct match between the company identifiers in the EUTL and in ORBIS is not possible, we use ORBIS's fuzzy search based on the installation owner's name. In the event of multiple results, we manually select the most feasible match. We disregard installations that could not be linked with a company's financial statement in the ORBIS database. In some cases, an installation is operated by a company that is not registered in the country in which the installation is located. These observations are also disregarded.

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[10] See, e.g. Gal (2013) who uses ORBIS for productivity calculations, Koch & Themann (2022) who study the impact of the EU ETS on firm productivity and Pak *et al.* (2019) who analyse the labour share in OECD countries.

[11] For non-euro countries, ORBIS converts value added to euro based on the average exchange rate of the relevant year.

[12] The data can be retrieved from http://www.oecd.org/sti/ind/stanstructuralanalysisdatabase.htm.

This paper analyses changes in emission intensity (measured in tonnes of CO_2-eq emitted, divided by value added) for industrial companies - excluding the power generation or utilities sectors[13] - between 2013 and 2019.[14] It therefore needs value added to be reported in both 2013 and 2019 for continuing firms. In addition, we exclude small firms with value added in 2013 or 2019 below €100 000. Overall, our analysis covers approximately 75 % of stationary EU ETS installations belonging to an industrial company, excluding the power generation sector. This represents approximately 70 % of emissions from stationary installations (see Online Appendix S1 for an overview of coverage per country). The main reason is that firms from several countries (e.g. the Netherlands or Greece) do not report value added in ORBIS and are therefore not included in the analysis.

We aggregate individual installations within a country and attribute them to the company operator. The emissions of a firm are calculated as the sum of the emissions of its installations. The activity attributed to the firm is the activity from the emitting EU ETS installation(s). If a single company operates multiple installations with different activities, we take the activity which is the source of the most emissions as the activity for the whole firm. Approximately 70 % of firms within our sample only operate one installation. While oil and gas are not included as an activity within the EU ETS (these installations are categorised as combustion), we assign operating companies with NACE 2-digit 6 to oil and gas.

2.2 Summary statistics

In total we analyse approximately 2 800 firms in 2013 and 2 500 firms in 2019. The number of installations and the quantity of emissions covered by our analysis do not differ significantly from one activity to another (see Online Appendix S2 for an overview of coverage per activity). Table 1 presents the summary statistics for the firms included in our sample.

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[13] NACE 2-digit code equal or below 33. This means that the power generation sector is excluded. Combustion installations, possibly generating electricity onsite, belonging to a company with NACE 2-digit code below 33 are included. NACE 2-digit codes below 10 predominantly include companies active in the upstream oil and gas sector that generally operate installations categorised as combustion.

[14] This period is chosen as 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.

Table 1 - Summary statistics of the used dataset

	2013	2019
Firms (number)	2 807	2 479
Single installation firms	1 984	1 719
Continuing	2 343	2 343
Exiting	464	
Entering		136
Installations (number)	4 910	4 441
Installations per firm (number)		
Mean	1.75	1.79
Median	1.00	1.00
P20	1.00	1.00
P80	2.00	2.00
Emissions per firm (in tCO_2-eq)		
Mean	163 139	183 124
Median	17 469	26 871
P20	4 766	7 424
P80	86 806	112 642
Value added per firm (in million EUR)		
Mean	97	117
Median	20	25
P20	5	6
P80	82	94
Emission intensity per firm (in tCO_2-eq per million € value added)		
Weighted mean	1 680	1 627
Mean	4 779	4 662
Median	1 207	1 415
P20	280	330
P80	4 702	4 640

Note: Value added in € million (in 2015 prices), emissions in tCO_2-eq, emission intensity in tCO_2-eq per € million value added. P20 and P80 refer to the 20th and 80th percentile of the distribution of the variable. Weighted mean uses share of total value added as weights (see equation 1, section 3). Source: Authors' calculations based on EUTL and ORBIS data.

The total emission intensity of industries regulated by the EU ETS (total emissions divided by the total value added or the mean weighted by a firm's share of value added) decreased from 1 680 to 1 627 tCO_2-eq per € million value added. The mean emission intensity also decreased. Furthermore, emissions intensity shows significant heterogeneity between all firms, which is apparent from the difference between the 20th (P20) and 80th percentile (P80). Even within carbon-intensive industries there are very large differences in the carbon emissions needed to generate economic value added. E.g. the production of cement or lime needs approximately ten times more carbon to generate the same value added as the production of glass or paper (Table 2). Table 2 shows that there is significant heterogeneity in emission intensity not only between activities but also within the same activity.

Table 2 - Summary statistics on heterogeneity of emission intensity within activities.

Activity	Observations (number of firms)	Emission intensity (in tCO_2-eq per million € value added)			
		Mean	Median	P20	P80
Combustion	1 680	1 719	525	85	1 960
Refining	109	18 063	6 699	1 455	14 445
Coke	11	55 023	14 296	9 581	38 306
Metal ore	25	4 338	2 431	770	6 772
Iron or steel	224	6 520	2 115	1 005	6 111
Ferrous metals	241	1 567	746	196	2 215
Primary aluminium	25	2 989	1 979	597	5 116
Secondary aluminium	33	1 060	848	403	1 500
Non-ferrous metals	104	4 146	612	159	2 323
Cement clinker	167	23 479	21 447	14 052	34 334
Lime	140	23 625	22 561	6 650	35 553
Glass	359	2 626	1 968	770	3 723
Ceramics	775	4 113	2 059	733	5 470
Mineral wool	81	1 822	1 377	578	3 087
Gypsum or plasterboard	51	1 314	854	378	1 495
Pulp	234	1 748	1 086	481	2 847
Paper or cardboard	492	2 514	1 610	430	3 456
Carbon black	15	18 908	5 761	1 888	12 953
Nitric acid	17	4 164	1 935	662	6 190
Adipic acid	2	2 019	2 019	1 309	2 729
Ammonia	20	14 190	12 376	3 537	21 142
Bulk chemicals	199	8 281	826	194	3 959
Hydrogen	26	6 173	1 151	293	10 355
Soda ash	12	8 081	7 474	1 912	13 194
Other	18	3 734	1 458	427	6 668
Oil and gas	226	5 264	1 475	307	6 866

Note: The full names of activities are listed in Appendix. Oil and gas are not an activity listed within the EU ETS. Firms with NACE 2-digit code 6 are attributed to oil and gas.
Source: Authors' calculations based on EUTL and ORBIS data.

3. Decomposition of the changes in carbon emission intensity

3.1 Methodology

To better understand the underlying processes that drive the change in emission intensity, we use well known techniques from the productivity literature that decompose changes in aggregate productivity into the contributions from continuing, entering, and exiting firms. The decomposition technique sheds light on the relative importance of the underlying processes of advancements within firms, reallocation between firms, and net entry of firms.

We use these techniques to decompose the change in aggregate carbon efficiency or "carbon productivity". We analyse changes in emission intensity, measured as the CO_2-eq emitted per unit of value added and distinguish between the contributions from continuing, entering, and exiting EU ETS firms.

The total emission intensity (EI_t) at time *t* is defined as the total emissions divided by the total value added of the industrial firms included in our dataset. This equals the weighted average of the emissions intensity ($ei_{i,t}$) of each firm *i* at time *t*:

$$EI_t = \sum_i \theta_{i,t}\, ei_{i,t} \qquad (1)$$

Where $\theta_{i,t}$ represents the share of value added of firm *i* at time *t* in the total value added of all firms in our sample and $ei_{i,t} = \frac{emissions_{i,t}}{value\ added_{i,t}}$ or the emission of firm *i* at time *t* divided by the value added of firm *i* at time *t.*

A first decomposition was proposed by Baily *et al.* (1992). Later, to overcome some issues stemming from this method, both Griliches & Regev (1995) and Foster *et al.* (2001) proposed different methods and decomposed productivity relative to a reference productivity level. More recently, Melitz & Polanec (2015) introduced an additional method. All methods decompose changes in productivity into three components. Firstly, the "within effect" or productivity improvements within continuing firms. Secondly, the "between effect" of continuing firms, which measures the variation of productivity following a change of market share or reallocation of activity between continuing firms. Thirdly, the "net entry effect" captures the contribution of entering and exiting firms. While other methods exist, we focus on these three commonly used methodologies[15] where we replace productivity by carbon intensity.

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[15] See Ben Hassine (2019) for a more detailed discussion of the three techniques.

3.1.1. GR method – Griliches & Regev (1995)

GR uses the average aggregate emissions intensity ($\overline{EI}$) between the two periods *t* and *t-1* as a reference.

$$\Delta EI_t = \underbrace{\sum\nolimits_{i\in C} \bar{\theta}_i \, \Delta ei_{i,t}}_{Within\,effect} + \underbrace{\sum\nolimits_{i\in C} \Delta\theta_{i,t}\left(\overline{ei}_i - \overline{EI}\right)}_{Between\,effect} + \underbrace{\sum\nolimits_{i\in N} \theta_{i,t}\left(ei_{i,t} - \overline{EI}\right) - \sum\nolimits_{i\in X} \theta_{i,t-1}\left(ei_{i,t-1} - \overline{EI}\right)}_{Net\,entry\,effect} \tag{2}$$

ΔIE_t (or $EI_t - EI_{t-1}$) corresponds to the change of aggregate emission intensity between the period *t* and *t-1*. EU ETS firms are indexed by *i* and may be classified as either continuing (C), entering (N), or exiting (X). $\theta_{i,t}$ denotes the activity share (the share of value added of firm *i* in the total value added of the included firms) and $ei_{i,t}$ the emissions intensity attributed to an individual EU ETS firm *i* in time period *t*. Bars over variables indicate that the average has been taken over the two time periods. Emission intensity is measured relative to value added, i.e. in tonnes of CO_2-eq emitted per unit of value added.

The contribution of the within effect is negative if continuing firms reduce their carbon intensity. The between effect is negative if firms that gain market share have a lower emissions intensity compared to the reference level. The net entry effect contributes negatively if entering (exiting) firms have a lower (higher) emission intensity relative to the reference. A drawback of the GR decomposition is that the within and between effects are interdependent given that the within effect uses average market share and the between effect uses the change of market share. The decomposition therefore does not separately take into account the reallocation of market share to companies that become more productive.

3.1.2. FHK method – Foster, Haltiwanger & Krisan (2001)

FHK overcomes this problem by introducing a covariance term or cross effect between market share and emission intensity. The reference level is the overall emission intensity in period t-1 (EI_t).

$$\Delta EI_t = \underbrace{\sum\nolimits_{i\in C} \theta_{i,t-1} \, \Delta ei_{i,t}}_{Within\,effect} + \underbrace{\sum\nolimits_{i\in C} \Delta\theta_{i,t}\left(ei_{i,t-1} - EI_{t-1}\right)}_{Between\,effect} + \underbrace{\sum\nolimits_{i\in C} \Delta\theta_{i,t} \Delta ei_{i,t}}_{Cross\,effect} + \underbrace{\sum\nolimits_{i\in N} \theta_{i,t}\left(ei_{i,t} - EI_{t-1}\right) - \sum\nolimits_{i\in X} \theta_{i,t-1}\left(ei_{i,t-1} - EI_{t-1}\right)}_{Net\,entry\,effect} \tag{3}$$

The covariance between productivity and firm size, represented by the cross effect, is negative when a company's emission intensity and market shares move in opposite ways. This implies that for a firm to contribute to a reduction in the cross effect, it needs to enhance its own carbon efficiency and acquire market share, even if its emission intensity is worse than the average. Essentially, this term highlights a reallocation process, though not necessarily favouring the least emitting firms. A drawback of FHK compared to GR is that it is more prone to measurement issues.[16] Furthermore, FHK might overestimate the contribution of entering firms as they are not included in the calculation of the reference emission intensity (EI_{t-1}).

3.1.3. MP method – Melitz & Polanec (2015)

Melitz and Polanec (2015) argue that the aforementioned techniques introduce some biases in the measurement of the contributions of entry and exit. They therefore propose a dynamic composition based on Olley and Pakes (1996).

$$\Delta EI_t = \underbrace{\Delta\overline{ei}_t}_{Within\,effect} + \underbrace{\Delta cov(\theta_{i,t}, ei_{i,t})}_{Cross\,effect} \tag{4}$$

$$+\underbrace{\sum_{i\in N}\theta_{i,t}\left[\sum_{i\in N}\frac{\theta_{i,t}}{\sum_{i\in N}\theta_{i,t}}ei_{i,t}-\sum_{i\in C}\frac{\theta_{i,t}}{\sum_{i\in C}\theta_{i,t}}ei_{i,t}\right]-\sum_{i\in X}\theta_{i,t-1}\left[\sum_{i\in X}\frac{\theta_{i,t-1}}{\sum_{i\in N}\theta_{i,t-1}}ei_{i,t}-\sum_{i\in C}\frac{\theta_{i,t-1}}{\sum_{i\in C}\theta_{i,t-1}}ei_{i,t-1}\right]}_{Net\,entry\,effect}$$

Where $\Delta\overline{ei}_t = \frac{1}{n}\sum_{i\in C} ei_{i,t} - \frac{1}{n}\sum_{i\in C} ei_{i,t-1}$ and $cov(\theta_{i,t}, ei_{i,t}) = \sum_{i\in C}(\theta_{i,t} - \overline{\theta}_t)(ei_{i,t} - \overline{ei}_t)$. A notable difference with the previous methods is that the within effect now measures a change in the unweighted average of the emission intensity of continuing firms. This cross term is also different than (and therefore not comparable with) the cross term from the FHK decomposition, which captures the covariance of market share and emission intensity *changes* for an *individual firm*. On the other hand, the MP covariance captures the correlation of market shares and emission intensity within a time period.

3.2. Results

Table 3 presents the change in emission intensity between 2013 and 2019. Emission intensity decreased by approximately 3 % over the period studied - from 1 680 (in 2013) to 1 627 (in 2019),[17] predominantly driven by reallocation. Table 3 decomposes the change in emission intensity according to the three methodologies described above. It breaks down the contribution of continuing firms into improvements within continuing firms (the within effect), reallocation (the sum of the between effects and the cross term), and net entry (the entry minus the exit effect). As there are no clear signs proving one method is better than the other, the range

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[16] This is due to the FHK cross term. Random measurement error in output yields a negative covariance between emission intensity changes and changes in output shares and therefore a spuriously high within effect. In contrast, the measured within effect from GR will be less sensitive to random error in output since it averages the share across time which mitigate the influence of measurement error.

[17] Emission intensity in tonne CO_2-eq per € million of value added. For reasons of simplicity, we omit the unit in the text.

given by the different methodologies could be seen as defining the extent of each component's contribution to the overall change in emission intensity. A reduction in emission intensity is noted with a negative number.

Table 3 - Decomposition of the change of emission intensity between 2013 and 2019

	2013	Within	Reallocation			Net entry			2019
			between	cross	between + cross	entry	exit	entry - exit	
GR	1 680	-1	-69		-69	-21	-38	17	1 627
		-0.1 %	*-4.1 %*		*-4.1 %*	*-1.3 %*	*-2.3 %*	*+1.0 %*	*-3.2 %*
FHK	1 680	56	-14	-114	-128	-22	-41	19	1 627
		+3.3 %	*-0.8 %*	*-6.8 %*	*-7.6 %*	*-1.3 %*	*-2.4 %*	*+1.1 %*	*-3.2 %*
MP	1 680	-2		-76	-76	-21	-46	25	1 627
		-0.1 %		*-4.5 %*	*-4.5 %*	*-1.3 %*	*-2.7 %*	*+1.5 %*	*-3.2 %*

Note: Emission intensity (2013 and 2019) in tCO_2-eq per million € value added. GR, FHK and MP refer to the used decomposition methodologies.
Source: Authors' calculations based on EUTL and ORBIS data.

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 the improvements of production processes over time. These improvements can be the result of innovation, the adoption of a new technology or measures that make existing technology and/or processes more carbon efficient. The within effect is close to zero for both GR and MP methods. This means that both the value added weighted change in emission intensity (GR, equation 2) and the unweighted change (MP, equation 4) is limited. The positive within effect from the FHK method is linked with the fact that FHK includes a cross term. The cross term can capture the fact that a firm can increase its market share and reduce its emission intensity at the same time. The fact that the within effect is close to zero or even slightly increasing overall emission intensity implies that improvements within firms to reduce their carbon intensity was, at best, very modest.

The reallocation term stems from changes in emission intensity in the market shares of the EU ETS firms. The reallocation effect is negative for all three methods. This means that production capacity is being reallocated from the most emission-intensive firms toward the less emission-intensive firms. The FHK cross term is indeed negative. This means that growing firms also reduced their emission intensity (e.g. growth leads to lower emission intensity via scale effects). The negative MP cross term must be interpreted differently. The negative correlation between emission intensity and size is higher (more negative) in 2019 than in 2013.

Additionally, the decomposition allows us to quantify the contribution to emission reductions due to net entry, which corresponds to the contribution of entry and exit. Entry reduces the average emission intensity if an entrant's intensity is lower than the average. Exit reduces average emission intensity if exiting firms have a higher emission intensity compared to the average. Here, the exit of underperforming firms allows the output to be reallocated to more carbon-efficient uses. Although the three methods calculate differently how a firm entering or exiting the market compares to the average, the results are similar. The contribution of net entry is modestly positive. This implies that the process when new firms push old firms out of the market did not contribute to reducing emission intensity.

3.3. Robustness

As explained in section 2 on data, we link installation-level emissions from the EU ETS with firm-level financial data. Not all the (carbon-emitting) installations of European manufacturing firms are included in the EU ETS: depending on the activity of the installation, there is a size threshold for inclusion in the system. In addition, if the activity of the installation is not carbon-emitting, it will not be regulated by the EU ETS. If a firm included in the EU ETS also operates installations not included in the ETS, we will potentially underestimate its total emissions and include value added generated by non-EU ETS installations. The result is that we underestimate the true emission intensity of the firm's carbon intensive activities, and the decomposition could be biased. Given that earlier we found that growth did go hand in hand with reducing emission intensity and that a non-EU ETS carbon emitting installation is smaller than an EU ETS installation, this aspect needs further study. Table 4 presents the same decomposition, but this time it is only for firms that operate a single EU ETS installation.[18] As the chances that a firm operates an installation not covered by the EU ETS increase with the number of those installations that are covered, these results will be less prone to underestimating emission intensity.

Table 4 - Decomposition of the change of emission intensity between 2013 and 2019 for firms with only one installation

	2013	Within	Reallocation			Net entry			2019
			between	cross	between + cross	entry	exit	entry - exit	
GR	1 369	-5	-15		-15	-38	-87	49	1 399
		-0.4%	*-1.1%*		*-1.1%*	*-2.8%*	*-6.4%*	*+3.6%*	*+2.1%*
FHK	1 369	41	32	-91	-59	-37	-85	48	1 399
		+3.0%	*+2.3%*	*-6.6%*	*-4.3%*	*-2.7%*	*-6.2%*	*+3.5%*	*+2.1%*
MP	1369	461		-492	-492	-40	-101	61	1 399
		+33.7%		*-35.9%*	*-35.9%*	*-2.9%*	*-7.4%*	*+4.5%*	*+2.1%*

Note: Emission intensity (2013 and 2019) in tCO$_2$-eq per million € value added. GR, FHK and MP refer to the used decomposition methodologies. Firms with a single EU ETS installation represent approximately 70% of firms and approximately 30% of emissions in our sample.

Source: Authors' calculations based on EUTL and ORBIS data.

A first finding is that the change in emission intensity remains small, but with opposite sign. Unlike the results including all firms, firms operating only one installation did not decrease their emission intensity. Possibly this is due to the fact that these firms have less opportunities for growth and growth is an important driver for increased carbon efficiency. Another reason might be that there are no technological spillovers possible

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[18] Single installation firms are firms operating only one installation throughout the period.

between multiple installations of the same firms. This could make it for a single installation firm more costly and hence less feasible to improve technology or production processes with respect to carbon emissions. We should also not rule out a reverse causality mechanism. Maybe these firms remain one installation firms and smaller compared to the average EU ETS firms simply because they did not manage to reduce emissions.[19] This would be a desired effect of the EU ETS.

Secondly, the GR and FHK show very similar patterns compared to the decomposition of all firms (Table 3). Only reallocation has a sizeable contribution in bringing intensity down. MP shows more extreme results with the within and reallocation component both large and compensating each other. This is likely due to the fact the MP is more prone to outliers given that the within component is calculated based on an unweighted average. The value added of smaller firms is relatively more variable between the two time periods. Excluding firms with multiple installations increases the relative number of small firms in the sample.

Another possible reason that our results do not fully capture the underlying evolution of emission intensity is the use of deflators. While we employed the most commonly used deflator for value added on the NACE 2-digit level that is available for all European countries, the average for a fairly broad sector will never be completely accurate at the firm level. We therefore also calculate emissions based on employment instead of value added. The advantage is that using employment as a proxy for output is not subject to the use of deflators. The disadvantage is that we do not correct for changes in labour productivity. Table 5 shows that the emission intensity calculated using employment increased by more than 10 % between 2013 and 2019. This result is probably biased upwards since we do not consider possible increases in labour productivity.[20] Quantitatively, the results closely resemble those based on value added. The within and net entry effects are positive, and the reallocation effect is negative. A noteworthy difference between the decomposition methods is the fact that MP within component (which is unweighted) is sizably more positive than GR and FHK (which is weighted by employment share). Smaller firms therefore saw their emission intensity go up more than larger firms. The MP cross terms also shows that size became increasingly correlated with lower emission intensity. This corroborates the finding from Table 4 that single installation firms performed worse with respect to reducing emissions intensity than multiple installation firms.

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[19] Or other reasons correlated with emission intensity.

[20] Within the EU-28, real labour productivity increased by approximately 6% between 2013 and 2019 according to Eurostat (nama_10_lp_ulc).

Table 5 - Decomposition of the change of emission intensity between 2013 and 2019 with emission intensity calculated based on employment

	2013	Within	Reallocation			Net entry			2019
			between	cross	between + cross	entry	exit	entry - exit	
GR	205	21	-5		-5	-4	-13	9	230
		+10.2%	*-2.4%*		*-2.4%*	*-2.0%*	*-6.3%*	*+4.4%*	*+11.7%*
FHK	205	22	-4	-1	-5	-4	-11	7	230
		+10.7%	*-2.0%*	*-0.5%*	*-2.4%*	*-2.0%*	*-5.4%*	*+3.4%*	*+11.7%*
MP	205	35		-19	-19	-4	-13	9	230
		+17.1%		*-9.3%*	*-9.3%*	*-2.0%*	*-6.3%*	*+4.4%*	*+11.7%*

Note: Emission intensity (2013 and 2019) is calculated as emissions (in tCO_2-eq) per person employed. Firms that do not report employment or report employment at below 5 heads in 2013 or 2019 are excluded.

Source: Authors' calculations based on EUTL and ORBIS data.

4. The untapped potential of reallocation to reduce carbon emission

In the previous section, we quantified the contribution of improvements within continuing firms (the within effect), reallocation (the between and cross effect), and net entry (the difference between entry and exit effect) to reductions in emission intensity. In this section, we focus specifically on the potential of reallocation to drive future reduction efforts.[21] And an effort will certainly be needed: the reduction in emission intensity of 3.2 % between 2013 and 2019 (Table 3) corresponds to a yearly reduction of approximately 0.5 %. This is well short of the 1.74 % p.a. linear reduction factor (LRF)[22] set during Phase 3 of the EU ETS (2013–2020); even further away from the 2.2 % p.a. LRF set for Phase 4 (2021–2030); and far off the latest European Commission decisions that increase the LRF to 4.3 % p.a. from 2024. In addition, Pisani-Ferry and Mahfouz (2023) estimate that French industry will need to reduce their emissions by 4.3 % p.a. to reach their 2030 targets. Based on these numbers, the reduction in industrial emission intensity will have to proceed at a drastically faster rate if targets are to be met *without* a substantial drop in industrial output.[23]

The within component of Table 3 (disappointingly) did not contribute sizably to the reduction in emission intensity.[24] This will undoubtedly change in the future as many governments push for the further development and adoption of new decarbonisation technologies. 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

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[21] The potential for further reallocation may be limited as cost-effective options might have been implemented already. Future emission reductions may require alternative approaches besides reallocation.

[22] The linear reduction factor (LRF) refers to the yearly reduction of the cap on total emissions within the EU ETS.

[23] The ETS reduction targets can also be met by further greening electricity production. Firstly, the drastic drop in carbon emissions stemming from electricity generation suggests that the low-hanging fruits have already been picked. Secondly, in France, given that the carbon intensity of electricity production is already low, there is limited scope to lower the carbon footprint of electricity generation.

[24] This finding is in line with Probst *et al.* (2021) who found that the average annual growth of climate change mitigation technologies slowed down significantly between 2013 and 2017, possibly driven by fossil fuel prices, low carbon prices, and increasing technological maturity for some technologies.

range of (government) support to develop further. The fact, however, that technologies that 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 across industrial installations within narrowly defined sectors. Indeed, for the free allocation of emission allowances, EU ETS industrial installations are subdivided into 54 categories[25] for which an emission benchmark is developed. This benchmark is based on the average emissions of the top 10 %, by performance, of 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 substantial emission reductions.

Indeed, we observed a significant heterogeneity in emission intensity not only within carbon-intensive industries (Table 1) but also within the narrowly defined activities under the EU ETS (Table 2).[26] This finding need not be surprising. It does not differ from the stylised fact that traditional sectoral productivity dispersion is high (and increasing) within European countries, possibly driven by slow technology diffusion (Berlingieri *et al*., 2020; CompNet, 2023). In addition, Capelle *et al.* (2023) find that sector heterogeneity in emission intensity within a country is much larger than the heterogeneity of total factor productivity.

Despite the significant heterogeneity, reallocation only reduced emission with 4% to 8 % (corresponding to 1 % to 1.5 % p.a.) between 2013 and 2019 (Table 3). Since reallocation plays a very strong role in increasing traditional productivity (see, e.g. Ben Hassine, 2019; CompNet, 2023), there is no reason to believe we can achieve emission intensity improvements of 4 % to 5 % p.a. without a sizeable contribution from reallocation. This could be from reallocation both within industry and within the different sub-segments of a (carbon-intensive) industry. The former corresponds to the change in consumption patterns needed to reach climate neutrality (Pisani-Ferry & Mahfouz, 2023) where final consumption substitutes consumption of carbon-intensive products with that of less carbon-intensive products. The latter corresponds to moving output towards less carbon-intensive producers of a similar product.

Reallocation within a sub-segment of a carbon-intensive industry (or activity listed in Appendix) also brings significant potential savings based on current production technology. To quantify this potential, we conduct a basic thought experiment (see Table 6 for the results). We split our sample of firms into two groups: a first group comprising the 80 % least carbon-intensive (or most carbon-efficient) firms within an activity and a second group comprising the 20 % most carbon-intensive (or least carbon-efficient) firms within an activity. We refer to this latter group as “brown zombies”.

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[25] 52 products and two so-called fallback approaches, based on heat and fuel.

[26] Installations are linked to an activity within the EU Transaction Log and not to one of the 54 categories used for the calculation of free allowances. Calculating the heterogeneity of emission intensity for these 54 categories is therefore not possible.

Our thought experiment now assumes that these brown zombies are pushed out of the market and that their output (measured in this exercise by value added) is taken over by the remaining firms with the same activity. These brown zombie firms represent less than 10 % of value added in our sample, but more than 40 % of emissions. The reallocation scenario assumes that the total output of each activity within the EU ETS remains constant, and that the output of the top 20 % of firms by emission-intensity (the "brown zombies") is now produced at the emissions intensity of the other 80 % of firms with the same activity. The emission-saving potential of such a reallocation exercise is substantial: the reallocated output of the bottom performers would now be produced with substantially fewer emissions. Overall emissions would drop by almost 40 %, whereas the total output that must be reallocated remains modest. The risk of stranded assets therefore remains limited.[27] Furthermore, Capelle *et al.* (2023) showed that brown zombies (or "climate laggards" as they refer to them) operate older physical capital stocks which further mitigates the impact of possible stranded assets.

To what extent is the savings potential from this reallocation exercise realistic? Our estimate of the "brown zombie" emission-savings potential depends heavily, of course, on the difference in emission intensity between the bottom 20 % and top 80 % of performers with respect to carbon efficiency within an activity. A large savings potential might stem from the fact that some activities regulated by the EU ETS (see the table in Appendix) are broadly defined and include firms producing very different products.

While there is certainly product heterogeneity within a single activity, we believe there is also substantial emission intensity heterogeneity within the production of similar products.[28] The design of the EU ETS is based on 52 benchmark technologies for products regulated under the system. Our data only allows us to split the sample in 26 activities, which implies that on average 2 different products[29] are produced within an activity. On the one hand, the results of our thought experiment are therefore an upper bound of the emission savings potential of reallocation. On the other hand, it remains a reallocation of 7 % of output. If all firms were to be forced to operate using the EU ETS benchmark technology based on the best 10 % of firms by emission intensity, 90 % of firms would be affected. The Box provides further evidence that firms within the EU ETS do produce similar products with very different emission intensities.

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[27] Next to stranded physical assets or capital, there is also a possibility that the climate transition leads to stranded human assets. While the overall negative effects of the reallocation of labour to green activities should remain manageable (Vandeplas *et al.*, 2022), this impact will be heterogeneous across geographical areas and types of workers (Bijnens *et al.*, 2022).

[28] Also, several authors have come to similar findings. As mentioned previously, Vieira *et al.* (2021) found significant differences in carbon abatement results between manufacturing firms carrying out the same activities. Capelle *et al.* (2023) found significant heterogeneity in environmental performance within the same industry and country. Furthermore, it is well documented in the productivity literature that there are large and persistent productivity differences across producers, even within narrowly defined industries (e.g. Bartelsman & Doms, 2000; Syverson, 2004; and more recently for Europe Berlingieri *et al.*, 2020; and CompNet, 2023). If productivity differences between similar firms are substantial and persistent, we find it reasonable to assume emission intensity differences between similar firms are also substantial and persistent.

[29] The European commission states that the benchmarks are based on the principle of 'one product = one benchmark'. This means that the methodology does not vary according to the technology or fuel used, the size of an installation or its geographical location.

What could drive the observed differences in emission intensity besides producing different products? Next to using different technology, an explanation is that some firms are better (i.e. in this context less carbon emitting) at using similar technologies and processes than other firms. Furthermore, some firms might have already started with (partially) electrifying[30] their production process. This would shift the firm's emissions within the EU ETS to the electricity producer (who is, if located within the EU also included within the EU ETS).[31] As such this is a desired process since electricity production has become less carbon intensive and its path to net zero is well understood. Furthermore, several studies[32] found evidence of a high degree of pass-through of a carbon tax or emissions costs to wholesale electricity prices. This ensures firms also pay for indirect emissions stemming from electricity generation. An undesired possibility is so-called carbon leakage. Carbon leakage refers to the situation where businesses transfer emission intensive production to other countries with laxer emission constraints. This could lead to an increase in their total emission intensity while our measured emission intensity comes down. In the past there has been found little proof, however, of significant carbon leakage (Verde, 2020).

Box - Similar products can be produced by firms with different emission intensities.

In this box, we provide examples of different firms regulated by the EU ETS that produce similar products but with different emission intensities. We focus on three homogeneous activities that produce commodities with limited possibilities to differentiate based on quality: manufacture of mineral wool; production or processing of gypsum or plasterboard; and production of soda ash and sodium bicarbonate.(a)

Table A presents the emission intensity for two firms undertaking each of these activities as well as their value added and number of employees. Based on the products promoted on their websites, these firms have similar product ranges.(b) To avoid results being driven by the volatility of value added in one particular year, we take an average over the 2013–2019 period. As a robustness check, we also calculate emission intensity based on number of employees instead of deflated value added. The firms are comparable in size but clearly have different emission intensities, calculated based on both deflated value added and on number of employees.

The reallocation exercise described earlier (with details in Table 6) would reduce emissions in the mineral wool, plasterboard and soda ash activities with 5%, 8% and 15% respectively for the same output.

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[30] Electrification refers to replacing technologies or processes that use fossil fuels with electrically-powered equivalents. Electrification is an important component of most, if not all, scenarios to become net zero. E.g., the International Energy Agency's Net Zero Scenario aims in the short term to increase the share of electricity in industry's global final energy demands increases from approx. 22% (in 2022) to 30% (in 2030).

[31] Note that outsourcing of emitting activities does not only reduce emissions, but also value added. Since we use value added as denominator for carbon intensity this partially covers the effect of outsourcing on emission intensity.

[32] E.g. Fabra & Reguant (2014) for Spain, Hintermann (2016) for Germany.

Table A - Comparison of emission intensity of two otherwise comparable firms within the same activity

Firm	Country	Emission intensity (value added)	Emission intensity (employment)	Emissions	Value added (deflated)	Value added (nominal)	Employees
Mineral wool 1	Hungary	3 698	153	27 155	7	7	178
Mineral wool 2	France	1 874	117	13 556	7	7	116
Plasterboard 1	Austria	915	102	21 826	24	24	213
Plasterboard 2	Poland	2 163	136	31 206	14	15	230
Soda ash 1	Germany	3 795	520	159 563	42	42	307
Soda ash 2	Bulgaria	6 094	1 461	693 036	114	110	474

Note: Value added in € millions (deflated to 2015 prices), emissions in tCO_2-eq, emission intensity (value added) in tCO_2-eq per € million value added, emission intensity (employment) in tCO_2-eq per person employed. All numbers are averages taken over the 2013–2019 period.

Source: Authors' calculations based on EUTL and ORBIS data.

(a) Producing soda ash is the first step in the production process of sodium bicarbonate, the two products are therefore always produced in combination.

(b) The names of these companies can be provided upon request.

Our definition of brown zombies – based on emission intensity – remains arbitrary. It corresponds to a scenario where reallocation is triggered by regulation that enforces a certain maximum emission intensity per activity. We can also define brown zombies in a manner closer to that used in the productivity literature where it is based on the financial condition of a firm.[33] We therefore conduct a similar thought experiment with brown zombies defined as firms that become cash-flow[34] negative in 2019 if all emissions are to be paid at €100/tonne CO_2.[35] This corresponds to a scenario in which reallocation is triggered by market-based policies. This most optimal path to carbon neutrality is likely to be a combination of market and non-market-based policies (Acemoglu *et al.*, 2016; Anderson *et al*, 2021).

Producing the output of brown zombies at the emissions intensity of non-zombie firms would now result in a 55 % emission saving (see Online Appendix S3 for detailed results). The main impact is the absence of free allowances in our thought experiment. In 2019, 70-80 % of the emissions of the firms in our sample were covered by freely allocated emission allowances. Brown zombies now represent approximately 20 % of value added and 70 % of emissions. This market-induced reallocation has a higher savings potential but involves the reallocation of a larger share of value added.

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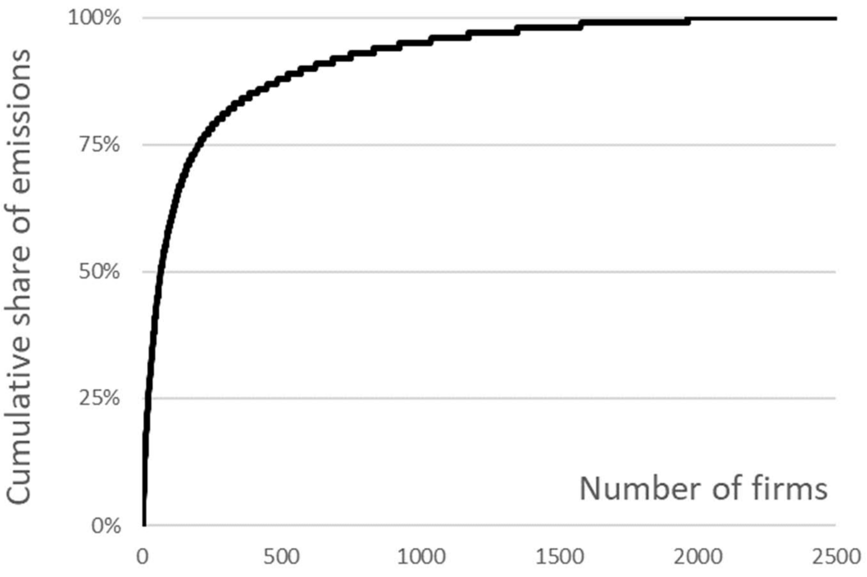
[33] Adelat McGowan *et al.* (2018) use interest coverage ratio to define zombie firms. Other definitions exist, e.g. firms with negative value added or negative profit.

[34] We use earnings before interest, taxed depreciation, and amortisation (EBITDA) to define cashflow.

[35] Note that this is defined ceteris paribus as it does not take into account an endogenous response by the firm such as passing through the increased emission costs to prices, or emission mitigation efforts, etc.

The preceding paragraphs outline two potential strategies for reallocation reflecting EU-wide policy measures applicable to all industrial enterprises. An alternative strategy could prioritise decarbonisation initiatives on the main emitting firms. A striking feature of this data is the extreme concentration of emissions among a relatively small subset of firms (see figure II). Specifically, merely 100 companies account for approximately 60 % of the total emissions in our dataset. Additionally, these firms are predominantly situated within a handful of industrial sectors, with two-thirds of them active in either refining, iron and steel, or cement industries. The opportunity for emission reduction by targeting these 100 companies is significant. While these companies are responsible for 60 % of emissions, they only contribute to 14 % of the overall output in our sample. Achieving emission levels on par with the remaining 2 379 companies could result in a 38 % reduction in emissions. Further details are provided in Online Appendix S4.

Figure II - Cumulative share of total emissions of firms included in the dataset



Note: Cumulative emissions from the 2 479 firms in the dataset described in section 2. The horizontal axis ranks the firms from most to least emitting and the vertical axis represents their cumulative emissions vis-à-vis total emissions.
Source: Authors' calculations based on EUTL data.

Table 6 - Reallocation exercise away from “brown zombies”

	80 % least emission-intensive firms				20 % most emission-intensive firms – “brown zombies”				Emission savings(1)	
	# firms	Value added	Emissions	Intensity	# firms	Value added	Emissions	Intensity	Emissions	% total
Combustion	621	165 062	17 760 229	108	159	4 449	27 136 280	6 099	26 657 580	59 %
Refining	40	24 166	56 603 202	2 342	10	1 148	23 755 133	20 693	21 066 212	26 %
Coke	4	57	1 377 279	24 163	1	1	49 870	49 870	25 707	2 %
Metal ore	10	899	2 420 491	2 692	2	749	5 775 289	7 711	3 758 662	46 %
Iron or steel	83	5 211	8 299 130	1 593	21	5 076	74 718 476	14 720	66 634 348	80 %
Ferrous metals	89	7 381	3 112 029	422	22	1 009	7 291 526	7 226	6 866 105	66 %
Primary aluminium	9	1 686	3 865509	2 293	2	123	1 047 211	8 514	765 208	16 %
Secondary aluminium	13	712	730 186	1 026	3	56	159 716	2 852	102 286	11 %
Non-ferrous metals	43	3 981	1 945 098	489	10	304	2 407 031	7 918	2 258 498	52 %
Cement clinker	64	4 957	69 913 969	14 104	16	367	15 243 223	41 535	10 067 022	12 %
Lime	52	1 441	14 975 566	10 392	13	46	2 059 478	44 771	1 581 424	9 %
Glass	137	6 894	10 357 700	1 502	35	853	3 985 795	4 673	2 704 229	19 %
Ceramics	278	5 356	7 888 791	1 473	71	291	2 058 235	7 073	1 629 624	16 %
Mineral wool	30	1 143	1 616 682	1 414	7	37	138 774	3 751	86 440	5 %
Gypsum or plasterboard	20	1 100	1 020 474	928	4	76	169 498	2 230	98 993	8 %
Pulp	88	7 335	4 254 649	580	22	342	1 307 165	3 822	1 108 789	20 %
Paper or cardboard	192	8 184	9 069 570	1 108	49	966	4 300 574	4 452	3 230 046	24 %
Carbon black	7	1 085	1 503 299	1 386	1	2	94 671	47 336	91 900	6 %
Nitric acid	7	542	1 627 898	3 004	1	1	22 488	22 488	19 484	1 %
Adipic acid	1	35	95 214	2 720	0					
Ammonia	8	749	10 146 416	13 547	1	16	694 956	43 435	478 210	4 %
Bulk chemicals	83	7 383	10 192 048	1 380	21	2 320	15 245 741	6 571	12 043 039	47 %
Hydrogen	11	1 507	2 405 103	1 596	2	58	1 846 508	31 836	1 753 943	41 %
Soda ash	4	200	1 378 128	6 891	1	95	1 008 094	10 612	353 483	15 %
Other	8	335	769 002	2 296	2	32	301 929	9 435	228 472	21 %
Oil and gas	81	13 230	11 714 743	885	20	665	8 103 617	12 186	7 514 781	38 %
TOTAL	1 983	270 631	255 042 405	942	496	19 082 *6,6%(2)*	198 921 278 *42,8%(2)*	10 425	171 124 485	38 %

(1) Emission savings (in tCO_2-eq, % of total emissions) if the bottom 20% most emission-intensive firms would produce the same output, but with the average intensity of the 80% least intensive firms.

(2) Represents the share in the percentage of value added or emissions of the 20% most emission-intensive firms in the value added or emissions of all firms Notes: Figures for 2019. Value added in € millions, emissions in tCO_2-eq, emission intensity tCO_2-eq per € million value added.

Reading note: A limited reallocation from the 20 % most emission-intensive firms (“brown zombies”) toward the 80% least intensive firms within sectors can decrease emissions by 38 %. This reallocation concerns 7 % of output.

Source: Authors' calculations based on EUTL and ORBIS data.

5. Conclusion and policy implications

Based on CO_2 emissions data from the EU ETS, we find that, unlike the electricity sector, manufacturing industry has not significantly reduced its emissions over the past decade. The prevailing thought is that, while the future path for electricity generation is clear, for the manufacturing sector there is uncertainty over the technologies that should be adopted and what their actual potential is for carbon abatement. This line of thinking risks opening the door to a “wait and see approach”. However, over the next decade, if the EU’s ambitious “Fit for 55” target is to be achieved, it will not only be necessary for the energy sector to decarbonise further, but the manufacturing industry will also have to significantly reduce its carbon footprint, and quickly.

While innovation and carbon efficiency improvements within existing firms are crucial for long-term climate neutrality, we propose that medium-term emission reduction targets may also be met through the reallocation of economic activity. This approach involves shifting production from the least emission-efficient firms ("brown zombies") to the most efficient ones. Reallocation, compared to the often lengthy process of developing and adopting new technologies, potentially makes it an alternative option for near-term emission reductions. However, the current discourse on industrial decarbonisation tends to prioritise the search for and adoption of new technologies, possibly overlooking the significant and more immediately accessible benefits of fully exploiting existing efficient technologies through reallocation of industrial production.

Our analysis reveals substantial variations in emission intensities within industries, with a subgroup of manufacturers contributing disproportionately to sector-wide emissions. We estimate that a significant reduction in carbon emissions -up to 38% in some cases- is possible through the reallocation of production among firms, without the need for new technology. This conclusion assumes that observed variations within narrowly specified activities are largely attributable to differences in technology or production processes rather than product distinctions. This assumption, though potentially not fully applicable to every industrial activity examined, offers an upper limit estimate for possible resource reallocation. Consequently, when designing emission reduction plans, policymakers must consider not only greening incumbent industrial firms but also the possibility that some companies may need to shrink or exit the market in favour of more carbon-efficient competitors.

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Appendix - Activities regulated under the EU ETS

Description of the activity	Shortened notation
Aircraft operator activities	Aircraft
Combustion of fuels	Combustion
Refining of mineral oil	Refining
Production of coke	Coke
Metal ore roasting or sintering	Metal ore
Production of pig iron or steel	Iron or steel
Production or processing of ferrous metals	Ferrous metals
Production of primary aluminium	Primary aluminium
Production of secondary aluminium	Secondary aluminium
Production or processing of non-ferrous metals	Non-ferrous metals
Production of cement clinker	Cement clinker
Production of lime, or calcination of dolomite/magnesite	Lime
Manufacture of glass	Glass
Manufacture of ceramics	Ceramics
Manufacture of mineral wool	Mineral wool
Production or processing of gypsum or plasterboard	Gypsum or plasterboard
Production of pulp	Pulp
Production of paper or cardboard	Paper or cardboard
Production of carbon black	Carbon black
Production of nitric acid	Nitric acid
Production of adipic acid	Adipic acid
Production of glyoxal and glyoxylic acid	Glyoxal
Production of ammonia	Ammonia
Production of bulk chemicals	Bulk chemicals
Production of hydrogen and synthesis gas	Hydrogen
Production of soda ash and sodium bicarbonate	Soda ash
Capture of greenhouse gases under Directive 2009/31/EC	Capture GHG
Transport of greenhouse gases under Directive 2009/31/EC	Transport GHG
Storage of greenhouse gases under Directive 2009/31/EC	Storage GHG
Other activity opted-in pursuant to Article 24 of Directive 2003/87/EC	Other

Source: EUTL.

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