Did ETS Coverage and Free Allowances Affect Economic Performance and GHG Emissions in the EU?: Evidence from a Panel of EU Sectors

ASLI AYDIN
Kadir Has University, Istambul, Turkiye *

SEVIL ACAR
Bogazici University, Istambul, Turkiye

This study analyzes the impacts of the European Union Emissions Trading System and free allowances on sectoral value added, gross output, and greenhouse gas emissions in the European Union for the period 1995-2020. Since the European Union Emissions Trading System inherently covers firm-level emissions, most studies in this area have been conducted at the firm level. However, a sectoral analysis allows understanding how sectors as a whole respond to the carbon pricing mechanism in terms of carbon reductions, competitiveness and sectoral output growth. It can also reveal how changes differ across sectors subject to different regulations. Controlling for sectoral employment, intermediate input use, and time effects, the results show that European Union Emissions Trading System coverage has a negative impact on both value added and gross output, but does not lead to a significant reduction in greenhouse gas emissions. The findings indicate that more labor-intensive and less input-intensive production can reduce emissions. Furthermore, the study draws attention to the competitive losses caused by compliance costs in sectors within the scope of the European Union Emissions Trading System and shows that the impact of free allowances on performance is insufficient. These results highlight the importance of coherent and inclusive approaches in policy design to more effectively manage the economic and environmental impacts of the European Union Emissions Trading System. It is recommended to develop more targeted and flexible strategies, taking into account sectoral differences.

Keywords: European Union Emissions Trading System; free allowances; greenhouse gas emissions; gross output; value added; sectoral performance

JEL Classifications: D24, N64, N74, Q54, Q58

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1 Introduction

The European Union Emissions Trading System (EU ETS) is one of the most well-known carbon pricing systems today. In addition to being the most important tool of the European Union (EU) policy to reduce greenhouse gas (GHG) emissions by at least 55% compared to 1990 levels by 2030, it also serves as an exemplary model for the global world by demonstrating a market-based mechanism for carbon reduction. Nevertheless, as the European Union advances its ambitious objective of achieving carbon neutrality through the ETS, a critical inquiry emerges: will this initiative impose a burden on industrial sectors, or could it instead represent a strategic opportunity?

This question is at the heart of many academic and policy debates. On the one hand, the EU ETS is highlighted as a way of forcing higher technological development in industries and thus innovation, while on the other hand, concerns are raised about production costs, reduced competitiveness and employment losses. This study aims to contribute to this debate by examining the impacts of the EU ETS at sectoral level on three key issues: carbon reduction, gross output and value added.

The need for a comprehensive assessment of the economic and environmental impacts of the EU ETS is becoming clearer as the system expands and grows in value. The EU ETS, as one of the world's first and largest carbon markets, reached €770 billion in 2023 in the total value, accounting for approximately 90% of the global carbon market (Reuters, n.d.). The scope of the system covers industrial activities, including electricity and heat production, which accounts for around 40% of total GHG emissions in the EU. It is to be expanded to include maritime coverage in 2024 (European Commission, 2018).

The operating mechanism is based on the *cap and trade* principle. Cap, expressed as emission allowances, limits the total amount of greenhouse gases and allowances can be sold in auctions and traded in the market. The aim here is to reduce allowance supply by reducing the cap level and thus reduce emissions. Since 2005, significant reductions in carbon emissions have been observed in the facilities it covers. In the facilities within the scope, the emission reduction was 22% between 2023-2024 and 50% between 2005-2024 (European Environment Agency, 2025). Investigating the extent to which the ETS contributes to this significant carbon reduction is a vital academic research question. Imposing financial burdens on firms to compel reductions in carbon emissions necessitates an examination of how companies, particularly those in carbon-intensive industries, respond. This is crucial for maintaining the overall economic equilibrium while achieving climate objectives. Although such financial pressures may incentivize investments in renewable energy and low-carbon technologies, they could also lead to substantial operational costs and reduced competitiveness for firms unable to adapt effectively. Furthermore, these dynamics risk prompting the relocation of production to countries with less stringent climate policies—a phenomenon known as carbon leakage—which undermines the EU's broader economic and environmental goals.

Given these dynamics, in this study, we address the environmental and economic impacts of the EU ETS at the sectoral level.

The key contribution of our study is its focus on sectoral level. Most of the relevant studies are conducted at the firm level, partly due to the nature of the EU ETS, which covers firm-level emissions instead of sectors. Despite this great challenge, a sectoral analysis can answer the question how sectors, as a whole, respond to a carbon pricing mechanism, particularly in terms of carbon reductions, competitiveness, and sectoral output growth. Moreover, such a comprehensive sectoral analysis may provide how these shifts may vary across sectors subject to different regulations.

The organization of the study is as follows: Section II presents the background and key milestones in phases of the EU ETS, highlighting the developments that might have had impacts on sectoral performance. Literature survey in Section III reviews existing studies that have different approaches in terms of environmental and economic impacts. Section IV describes the data utilized in the analysis, presents the data sources and provides the key descriptive statistics. In Section V, the empirical strategy is provided and the results are presented. Section VI discusses the results and puts forward policy recommendations. Section VII concludes.

2 Phases and Trends in the EU ETS

The EU ETS system consists of various phases, both to allow companies sufficient adaptation time and to conduct the carbon allocation mechanism effectively (Table 1). As a pilot period, Phase 1 (2005-2007) mostly provided free allocations to the covered sectors, which included energy-intensive industrial facilities such as cement, iron and steel, aluminum, petrochemicals, chemicals, glass-ceramics-paper. Phase 1 represents a significant period in the establishment of the carbon market. Although it introduced a carbon price and provided the framework for emissions trading, the lack of reliable emissions data led to the over-allocation of permits. This oversupply led to the carbon price falling to zero by 2007, highlighting the need for a more structured approach in future phases (Figure 1).

In Phase 2 (2008-2012), free allowances for electricity generation were completely abolished and share of free allowance for industries was reduced to 90%. Moreover, sectoral coverage was expanded. Phase 2 incorporated the aviation sector, albeit in a limited capacity and primarily restricted to monitoring activities. In Phase 3 (2013-2020), 40% of allowances were auctioned, pushing electricity producers to buy all of their allowances (with exceptions in some member states like Poland, Bulgaria, Hungary, Lithuania, etc.). As of 2024, free allocation prevailed in manufacturing (80%) and aviation (85%), and sectors deemed to be at risk of ‘carbon leakage’ also received an extra amount of free allowances (Appunn and Wettengel, 2023).

Table 1. Evolution of the EU ETS

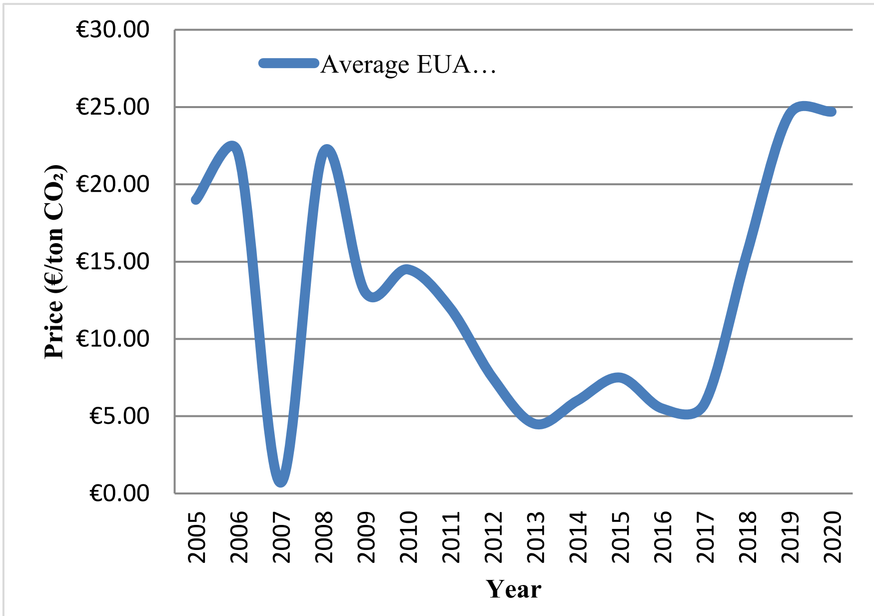
ETS Phases (Years)	Covered Sectors	Free Allocation Mechanism	Penalty	Average Allowance Price (EUR/tCO_2e)
Phase 1 (2005-2007)	Electricity production, industrial manufacturing (cement, steel, refineries, chemicals, paper, glass, ceramics)	100% free allocation for all covered sectors	40 EUR	13.27
Phase 2 (2008-2012)	Electricity production, industrial manufacturing, partial aviation coverage (monitoring only)	90% free allocation for industries, electricity production phased out	100 EUR	13.56
Phase 3 (2013-2020)	Electricity production, industrial manufacturing, full aviation coverage (intra-EU flights)	Industries' free allocation reduced, none for electricity, partial for aviation.	100 EUR	11.67

Source: European Commission, *Climate action*. European Commission. https://climate.ec.europa.eu/

Phase 3 can be characterized as more aggressive in decarbonization targets. Auctioning nearly became the default allocation method during this period and sectoral gas coverage has been expanded. The carbon market grew significantly in a short period of time, with trading volumes increasing from 3.1 billion permits in 2008 to 7.9 billion in 2012.

How all these measures and the expanding carbon market are reflected in carbon prices is a relevant question to be investigated. Looking at the historical trends of carbon prices, we may define Phase 2 as a period overshadowed by the stagnation problems of the 2008 crisis after the over-allocation problem in Phase 1 that resulted in significantly low carbon prices. It is clear that a robust price signal was not formed in the first two phases due to both the design deficiencies of the ETS and the effect of the general macroeconomic conjuncture. In Phase 3, especially by 2017, the market experienced an upward movement of prices. This can be associated with 1) the acceptance of the Market Stability Reserve (MSR) mechanism, which showed that excess emission permits would be withdrawn from the system and provided confidence to the market, and 2) the announcement that the annual emission reduction rate would be increased from 1.74% to 2.2% (European Commission, 2018).

Figure 1. European Union Allowance (EUA) prices over the years 2005-2020



Source: Authors' calculation from European Environment Agency

Considering the high prices that occurred especially after Phase 3, investigating the impacts on economic performance and environmental outcomes of the sectors and distinguishing between how much of these impacts are due to the EU ETS are deemed to be important for the continuity, progress, and evolution of climate policies.

In order to understand the sectoral effects of the EU ETS, it is necessary to start from the system's operating mechanism. The EU ETS limits total GHG emissions by setting an emission cap and allowing the trade of emission allowances. This basic mechanism can have opposing effects on sectoral economic performance and environmental outcomes. This simple mechanism may have opposing impacts on economic and environmental outcomes.

First, pricing emission rights poses both costs and opportunities for sectors. On the one hand, the carbon cost added to production processes increases operational costs, which can negatively affect value added and gross production. Especially in carbon-intensive sectors, this additional cost is expected to be high and therefore may reduce sectoral performance in the short term. On the other hand, carbon pricing can create a competitive advantage for sectors by increasing the willingness to invest in low-emission technologies and can provide efficiency gains in the long term. However, whatever the direction of these impacts is, the effect of the EU ETS depends on the proper determination of the emission caps.

On the other hand, adaptation processes involving adverse effects such as sudden financial shocks are quite challenging for firms. Free allowances are designed to mitigate these potential difficulties and protect industries from competition losses. Yet, at the same time, free allowances may undermine environmental efficiency by alleviating financial pressure for emissions reductions. In this case, the economic benefits in sectors receiving free allowances may be more limited and emissions reduction performance may remain low.

From a sectoral analysis perspective, employment and intermediate input use are also expected to be determinants of environmental impacts. In this context, labor-intensive production processes are generally expected to produce less carbon emissions than energy-intensive processes. Conversely, increasing intermediate input use – particularly increased energy and raw material consumption – might increase emissions.

3 Literature Survey

Since the declaration of the EU ETS system in 2005, its impact on different sectors has been the subject of wide observation and academic research. It is of critical importance to examine the consequences of carbon pricing and market-based approaches in terms of competitiveness and environmental sustainability. In this section, we review the main findings on the impact of the ETS on sectoral performance in EU countries, particularly by examining the literature on productivity, employment, investment, profitability and carbon emissions.

3.1 Abatement impacts

Greenhouse gas reduction is one of the most important goals of the EU ETS. Although a significant decrease has been seen in various sectors since 2005, isolating how much of this decrease is due to the ETS is a process that requires complex methods.

Several of the relevant studies adopt a generalized decomposition approach, quantifying emission reductions by comparing the emissions projected under firms' business-as-usual activities with their actual emissions following their integration into the ETS (Ellerman and Buchner, 2008; Delarue et al., 2008a). Similarly, Müller and Sacco (2025) found that the residual reduction required after offset credits were used for the second and third phases as of 2008 was 38 Mt, implying an emissions level below the ETS cap in the period 2009–2012.

As the EU ETS developed across phases with tighter caps and reduced free allocations, research findings differed on system efficiency. Laing et al. (2014) found that excess supply and price volatility reduced system efficiency despite emissions contributions, while Abrell et al. (2011) documented particularly strong reductions in the metals sector but minimal impacts in the electricity sector in Phase II. Pietzcker et al. (2021) predict that tightening targets will accelerate the phase-out of coal.

However, allocation mechanism failures and external factors complicate the effectiveness assessment. Over-allocation of rights in the early stages weakened the incentives for emission reductions (Anderson and Di Maria, 2011). More critically, Koch et al. (2014) and Klemetsen et al. (2020) argue that post-crisis carbon reductions were largely driven by the economic recession and renewable energy policies rather than ETS mechanisms.

3.2 Impacts on Industrial Output and Employment

The literature on the impact of the EU ETS on economic performance is structured around two main approaches. The Porter Hypothesis argues that environmental regulations can provide a competitive advantage in the long run by forcing firms to innovate. Among the studies supporting this view, Brännlund et al. (1998) predict an increase in competitiveness in the Swedish paper sector in the long run despite short-term negative effects. Costantini and Mazzanti (2012) find productivity gains reflected in value added per worker, Dechezleprêtre et al. (2018) find revenue and profit increases and Segura et al. (2018) find a 3.8% operational efficiency improvement. Studies focusing on green innovation also support this view. While Ju et al. (2024) find that green technology investments increase return on assets, Castro et al. (2021) show that strong environmental performance positively affects stock prices and value added.

In contrast, studies from a cost burden perspective focus on the short-term negative effects of the EU ETS. Studies show that production cuts have become the main emission reduction strategy and that significant industrial production value losses have occurred (Zhang et al., 2020). Regarding employment, there are conflicting findings: some studies argue that environmental policies shift employment from polluting industries to green sectors (Marin and Vona, 2019), while others document employment declines and sectoral value-added contractions due to cost increases in energy-intensive industries (Commins et al., 2011).

These conflicting findings suggest that the EU ETS has heterogeneous sectoral effects and that the time horizon is critical. The fact that the existing literature mostly focuses on firm-level analysis suggests that aggregate sectoral effects have not been sufficiently investigated. This study aims to fill this gap by examining sectoral impacts on gross production, value added and greenhouse gas emissions and to provide a comprehensive perspective on how carbon pricing mechanisms affect industry sectors.

This study undertakes a sector-level analysis to fill the gap created by the firm level focus in the existing literature. The main reason for conducting analysis at the sectoral level is to capture aggregate effects that firm-level studies may miss. While firm-level analyses can examine individual firm responses to the ETS in detail, they may not fully capture indirect effects resulting from interactions among firms within a sector, market balances, and competitive dynamics. Thus, the sectoral approach provides a more comprehensive perspective for policy makers by assessing the net impact of carbon pricing on the overall performance of a sector.

4 Exploratory Data on Sectoral Economic Activity, GHG Emissions, EU ETS Coverage and Free Allowances in the EU

The current analysis investigates the period 1995-2020 for economic performance and 2008-2020 for GHG emissions. The NACE Revision 2 sectors included in the analysis are coded in letters as in Table 2.[1]

By setting a cap on total emissions and allowing permit trading, the EU ETS aims to cost-effectively reduce greenhouse gas emissions and encourage investment in low-carbon technologies. The system targeted CO_2 emissions from high-emission facilities in the power and heat generation industry as well as selected energy-intensive industrial sectors. The scheme has evolved over time widening its scope and applying some initiatives in order to increase the effectiveness of climate mitigation. 'Electricity, gas, steam; water supply, sewerage, waste management' (code *D* in Table 2) has historically been the most carbon-intensive sector. It is followed by 'Manufacturing' (code *C*), 'Agriculture, forestry and fishing' (code *A*) and 'Transportation and storage' (code *H*), according to the EUKLEMS & INTANProd database (2023 release) .

'Electricity, gas, steam; water supply, sewerage, waste management' received free allowances between 2005 and 2012. Electricity producers have been obliged since 2013 to buy all the allowances they need to generate electricity. However, some EU Member States may grant free allocations to electricity-generating installations as part of efforts to modernize their energy sectors.

'Manufacturing' has been receiving free allowances since 2005. Manufacturing industries will continue to receive a share of their emission allowances for free beyond 2020. This allocation is based on benchmarks that reward most efficient installations in each sector. Manufacturing industry obtained 80% of its allowances for free in 2013. This proportion decreased gradually year-on-year, down to 30% in 2020.

Tables 3 and 4 present the abbreviations, definitions, and units as well as the summary statistics of the variables used in the analysis. We use the natural logarithms of the non-binary variables throughout all the econometric regressions in Section V.

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[1] EUKLEMS & INTANProd database (2023 release) classifies 'Electricity, gas, steam; water supply, sewerage, waste management' under the code *D and E*; but here we denote it as *D* for simplicity. Similarly, 'Professional, scientific and technical activities; administrative and support service activities' are aggregated under the code, *M and N;* but here it is denoted as *M* for simplicity.

Table 2. Sectoral Coverage of the Analysis

I - 'Accommodation and food service activities'
A - 'Agriculture, forestry and fishing'
R - 'Arts, entertainment, recreation; other services and service activities, etc.'
F - 'Construction'
P - 'Education'
D - 'Electricity, gas, steam; water supply, sewerage, waste management'
K - 'Financial and insurance activities'
Q - 'Human health and social work activities'
J - 'Information and communication'
C - 'Manufacturing'
M - 'Professional, scientific and technical activities; administrative and support service activities'
O - 'Public administration and defence; compulsory social security'
L - 'Real estate activities'
H - 'Transportation and storage'
G - 'Wholesale and retail trade; repair of motor vehicles and motorcycles'

Note: Despite being covered by the EU ETS and receiving FA, aviation or air transport is not included in sector *H* due to data unavailability. Also, no data was available for 'Mining and quarrying'.

Table 3. Abbreviations, definitions, and units of the variables used in the analysis

Variables and units	**Abbreviation**
Gross value added, fixed prices, billions of EUR	VA_FP
Gross output, fixed prices, billions of EUR	GO_FP
Intermediate inputs, fixed prices, billions of EUR	II_FP
Number of persons employed, millions	EMP
Greenhouse gas emissions, million tonnes CO_2e	GHG
1 if covered by EU ETS; 0 otherwise	ETS
1 if free emissions allowances are received by sector; 0 otherwise	FA

Source: EUKLEMS & INTANProd database, 2023 release

Table 4. Summary statistics, using the observations used in the analysis

Variable	**Mean**	**Median**	**S.D.**	**Min**	**Max**
VA_FP	690	558	419	172	2034
GO_FP	1444	1099	1319	352	6764
GHG	228	32	358	5	1360
II_FP	754	418	968	115	4761
EMP	13	11	9	2	35
ETS		0		0	1
FA		0		0	1

5 Method and Results

The empirical model is a standard panel-data fixed-effects regression. Let *i* indexes sectors and *t* indexes years. The main explanatory variable is ETS_{it}, which equals 1 if sector *i* is covered by the EU ETS in year *t*, and 0 otherwise. We estimate the following panel fixed-effects form:

$$y_{it} = \varphi ETS_{it} + \beta' X_{it} + \delta_t + \alpha_i + \varepsilon_{it}$$

where y_{it} is the dependent variable, taken in logarithms. In the first set of specifications, y_{it} denotes value added in fixed prices (*VA_FP*); in the second, gross output in fixed prices (*GO_FP*); and in the third, greenhouse gas emissions (*GHG)*. The vector X_{it} contains the control variables, also in logarithms: intermediate input value in fixed prices (*II_FP*) and employment (*EMP*). The term δ_t represents year fixed effects that capture shocks common to all sectors, and α_i represents sector fixed effects capturing all time-invariant sector-specific characteristics. The error term is denoted by ε_{it}. This specification is equivalent to regressing y_{it} on ETS_{it}, the controls, and a full set of year dummies, while absorbing sector-specific fixed effects. The same model structure is used when replacing ETS_{it} with the variable FA_{it} to estimate the impact of free allowances on *VA_FP, GO_FP,* and *GHG* respectively.

To account for cross-sectional dependence in disturbances, as well as heteroskedasticity and autocorrelation, we use the spatial correlation consistent estimator introduced by Driscoll and Kraay (1998). Serial correlation is managed using the Newey–West (1987) approach. To avoid multicollinearity, we first check for the correlation coefficients and notice that there was no high correlation between the independent variables.[2] Besides, to account for time-dependent effects, time dummies are added to each panel regression equation. According to the results of the Hausman (1978) tests computed for each equation, the null hypothesis (H0: GLS estimates are consistent) is rejected and therefore it is inferred that the random effects estimator is inconsistent. Hence, the fixed effects specification is selected for analysis.

Table 5 shows the fixed effects estimation results for the three dependent variables in separate models (i.e. Models 1, 2, and 3 respectively) (Detailed regression outputs are available from the authors on request.)

The results reveal that the effect of ETS coverage on both Value Added and Gross Output is negative; that is, ETS coverage significantly reduced sectoral *VA_FP* and *GO_FP* (Models 1a and 2a) during the investigated period. Because the dependent variables are in natural logarithms, coefficients can be interpreted as approximate percentage changes. For precision, we convert log-point estimates into exact percentage changes using $(e^{\beta}-1)*100$. Given the small magnitude of the coefficients, the approximate and exact values differ by less than the third decimal place.

[2] Detailed info is available from the authors on request.

Table 5. Fixed effects estimation results for *VA_FP, GO_FP*, and *GHG*

	Model 1a VA_FP	**Model 1b VA_FP**	**Model 2a GO_FP**	**Model 2b GO_FP**	**Model 3a GHG**	**Model 3b GHG**
II_FP	0.70***	0.68***	0.86***	0.86***	0.45***	0.42***
	(0.07)	(0.08)	(0.04)	(0.04)	(0.07)	(0.09)
EMP	0.15***	0.17***	0.07***	0.08***	-0.67***	-0.63***
	(0.04)	(0.04)	(0.02)	(0.02)	(0.07)	(0.08)
ETS	-0.06***		-0.01***		-3.65	
	(0.01)		(0.003)		(2.68)	
FA		-0.02		0.0005		0.07
		(0.02)		(0.008)		(0.05)
constant	2.73***	2.69***	2.00***	1.99***	17.42***	16.97***
	(0.77)	(0.78)	(0.37)	(0.38)	(0.67)	(0.67)
time dummies	yes	yes	yes	yes	yes	yes
observations	315	315	315	315	182	182
LSDV R-squared	0.996	0.996	0.999	0.999	0.999	0.999
Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1						

Source: Authors' own calculation. All variables (except ETS and FA) in logs. Standard errors in brackets.

Since *$(e^{0.06}-1)*100$* makes around *−5.8236%,* being covered by the EU ETS reduced sectoral value added by approximately 6%. Similarly, as compared to the non-ETS category, being covered by the EU ETS led to a decline in sectoral gross output by 1%.

The effect of FA on both Value Added and Gross Output is always insignificant; that is, FA neither decreased nor increased sectoral *VA_FP* and *GO_FP* (Models 1b and 2b).

As expected, higher employment and intermediate input levels are associated with higher sectoral performance, in terms of both output and value added (Models 1a to 2b).

On the other hand, the effects of both ETS coverage and free allowances on GHG emissions are insignificant; that is, ETS coverage or free allowances did not lead to a significant emissions decline in the investigated sectors (Models 3a and 3b). Higher employment led to a decline in emissions, whereas higher intermediate input levels are associated with higher emissions. To be more precise, a percentage increase in employment led to a net decline of 0.6%-0.7% in GHG emissions, whereas a percentage increase in intermediate input use led to a net increase of 0.4%-0.5% in GHG emissions (Models 3a and 3b). This implies that more labour-intensive and less input-intensive production has led to lower emissions in time.

6 Discussion and Policy Implications

Our findings on *gross output* are generally consistent with, but in some cases differ from, previous findings in the literature. For example, Petrick and Wagner (2014) and Löschel (2019) report that the EU ETS has no significant negative impact on employment, production, and exports in manufacturing firms in Germany. In contrast, Zhang and Duan (2020) show that the ETS has a negative impact on industrial gross output. In addition, Borghesi et al. (2019) and Böning et al. (2023) draw attention to the anti-competitive effects of the ETS. These studies show that the regulations under the EU ETS lead to more significant gross output losses in companies sourcing inputs with high carbon footprints within the EU.

Our findings on *value added* are consistent with the results of Zhang and Duan (2020), but there are conflicting findings on value added in the firm-based literature. For example, Klemetsen et al. (2020) find that the EU ETS reduced emissions and increased value added and labor productivity in Norwegian facilities during the second compliance period. Similarly, Marin et al. (2018) find a positive impact on value added in a large panel of European firms in the second phase of the EU ETS. However, Abrell et al. (2011) show that inclusion in the ETS had no significant impact on profitability, employment, or value added for 2,101 European firms in the first and early second phases of the ETS.

These results highlight the complexity of the sectoral effects of the ETS and the importance of different dynamics in the regulated sectors. Besides, they reflect the complexity and heterogeneity of the effects of the ETS and FA on output, value added, and GHG emissions across different compliance periods and geographical contexts.

Being within the scope of the ETS reduced the value added of the sectors and gross production in the investigated period, which could be due to factors such as the increase in operational costs of the sectors in the ETS due to compliance costs, the reduction or relocation of production abroad in order to remain competitive (Delarue et al., 2008b; Denny and O'Malley, 2009; Veith et al., 2009). In addition, the insignificance of the impacts on GHG emissions could be explained by emissions leakage (moving emissions-intensive production outside the EU) or the ETS being insufficiently stringent. These findings bring together several policy recommendations: Considering the economic burdens faced by sectors in the ETS, policymakers should develop mechanisms to support innovation and modernization. Furthermore, the ETS should be aligned with complementary policies such as stricter regulations or energy efficiency incentives to be more effective in promoting emission reductions. Han et al. (2022) illustrate how government subsidies for R&D affect pricing and environmental sustainability decisions in green supply chains. In this line, also the establishment of energy efficiency standards for buildings provides an efficient policy example. These standards aim to significantly reduce energy consumption, complementing the ETS by reducing the overall demand for carbon-intensive energy sources. (IEA, 2023)

The impact of free allowances on both value added and gross output is generally insignificant, suggesting that free allowances neither increase nor decrease industry performance. Possible reasons for this include that free allowances fail to fully offset compliance costs and reduce firms' incentives to invest in low-carbon technologies. In addition, allocations based on past emissions (i.e. grandfathering) may not reflect current industry dynamics and may limit their effectiveness. Policies could improve cost-effectiveness of free allowances and encourage innovation by switching to auction-based allowances or output-based benchmarks. In addition, free allowances could be better targeted to protect the competitiveness of vulnerable industries without compromising environmental goals. In particular, sector-specific allocation mechanisms that take into account trade levels and carbon intensity can be targeted (Fischer and Fox, 2010).

Higher employment levels and use of intermediate inputs are found to positively affect sectoral performance in terms of both output and value added, while the effects on GHG emissions differ. Higher employment leads to a reduction in GHG emissions, while higher use of intermediate inputs leads to an increase in emissions. According to the IEA's Net Zero Emissions Scenario by 2050, clean energy-related industries need an additional 16 million jobs, and when indirect impacts are included, the clean energy target could be met by 2030 with more than 30 million new jobs.

Also, findings suggest that more labor-intensive and less input-intensive production leads to lower emissions over time. Policies that encourage employment and labor-intensive production can provide double-sided benefits in terms of both economic performance and emission reductions. In terms of intermediate inputs, practices such as circular economy initiatives or green supply chains may gain importance to encourage sectors to shift to clean inputs or to increase process efficiency. Adopting the principles of the circular economy brings about decoupling from economies that use limited resources, and the efficiency gain to be achieved here is measured as a reduction of approximately 30% in total resource use (Circle Economy, 2023).

7 Conclusion

Our findings indicate that the EU ETS had negative, though relatively modest, effects on sectoral gross output and value added over 1995–2020, and had almost no measurable impact on reducing GHG emissions during 2008–2020. This provocative result should be treated with caution. The ETS imposes a burden on businesses directly through permit purchase costs and indirectly through increased energy prices. Sectors with limited flexibility to reduce emissions may be disproportionately affected in terms of competitiveness, growth and value added. Furthermore, emissions may have been shifted to sectors or regions not covered by the ETS rather than actually reduced (carbon leakage), which may explain the lack of observed emission reductions. In the short term, the costs of switching to low-emission technologies may outweigh the immediate gains, especially if longer-term benefits require more time. Insufficient stringency or overly generous allowances at some stages of the ETS may have sustained economic costs while weakening important emission reduction incentives. Furthermore, sectors differ in their capacity to adapt, and the aggregate results may mask these differences. Energy-intensive sectors in particular may have been more affected by the costs of the ETS, overshadowing potential benefits in other sectors. The European Court of Auditors (2020) assessed the free allocation of allowances under the EU ETS. In parallel to the current study, it found that during Phase 3 (2013–2020), free allowances did little to promote decarbonization, particularly in the power sector. The allocation method lacked sufficient targeting to drive emissions reductions, and better targeting could have enhanced decarbonization, public finances, and market efficiency. Understanding these dynamics requires sector-by-sector analysis, and it is important to understand whether negative outcomes are temporary or systemic. Furthermore, policy adjustments, such as targeted support for affected sectors or tighter limits, can improve the balance between economic and environmental goals.

The limitations of this study and future research avenues suggest that the effects of climate regulations on sectoral performance and GHG emissions should be examined more comprehensively. The inputs and employment variables used in our study can only partially explain the variations in VA, GO, or GHG. For example, excluding other relevant factors such as technology, capital stock, or managerial efficiency could bias the estimated relationships; however, these variables could not be included in the analysis due to data limitations. Similarly, differences in the quality of inputs (e.g., skilled versus unskilled labor or high-quality versus low-quality intermediate goods) were ignored in the regression analysis. Demand-side factors (e.g., consumer preferences, trade dynamics) are also influential on value added and gross output (UNIDO, 2019); but they were not considered in this study. It should also be noted that factors such as subsidies, taxes, or trade barriers may have effects on VA, GO, or GHG independent of inputs, which may lead to omitted variable bias.

The EU ETS encompasses only a portion of emissions within each sector, meaning that numerous installations fall outside its scope and can therefore act as a potential control group for causal analyses that will be conducted in the future. Moreover, our approach of treating the manufacturing sector homogeneously creates important limitations. Evaluating high carbon-intensive industries like steel and cement together with low carbon-intensive sectors like electronics and textiles masks the heterogeneous effects observed at firm-level in the literature and complicates the identification of specific policy needs Therefore, in future studies, at least making a distinction between energy-intensive and non-energy-intensive manufacturing sectors may provide a more detailed sectoral analysis that will complement firm-level findings in the literature.

Future research could use different analysis methods and indicators depending on data availability. For example, instead of output or value added, sectoral productivity could be considered as a performance indicator. One example from the literature belongs to Koch and Themann (2022), who report that the EU ETS had no significant impact on total factor productivity in eight EU countries during the period 2002–2012. Similarly, investments could be used as a dependent variable, but this would require additional data on the factors that determine investments (e.g., education, R&D). Finally, by conducting sector-specific or firm-level analyses, differences in production processes and factor intensities could be examined in more detail. Such studies could provide critical ground for more detailed assessments of the performance of sectors under the ETS and better guide policy recommendations.

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