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THE IMPACT OF THE EU ETS ON GREENHOUSE GAS EMISSIONS IN THE EU FROM 2005 TO 2022

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ABSTRACT: Although there is an abundance of research focused on the European Union Emissions Trading System (EU ETS), there are only a few long-term studies on this theme. The majority of the studies examine the first two phases of the EU ETS. Our approach is different, we use the latest data available and analyse the EU ETS throughout all four phases from 2005 to 2022. The aim of this paper is to investigate the impact of the EU ETS on greenhouse gas emissions in the EU27. Examining its effectiveness is essential for better adjustment in the future to meet the EU's 2030 greenhouse gas emissions target and the EU's 2050 net-zero target. We set a research question: Was the EU ETS effective in reducing overall CO_{2e} emissions in the EU27 in the period 2005-2022? We applied two regression models and can confirm that total investment, corporate investment, price of emission allowance, and time are statistically significant and have an impact on the CO_{2e} emissions in the EU27. The results show that the EU ETS led to a 42.8% reduction in CO_{2e} emissions between 2005 and 2022. Our findings suggest that the EU ETS has become an effective tool in the transition to a low-carbon future within the sectors included in the system.

KEYWORDS: European Union Emissions Trading System, climate policy, investment

Introduction

The European Union has gradually expanded and revised the European Union Emissions Trading System (EU ETS), which is a key element of the EU strategy in the fight against climate change. The EU ETS has been adjusted with an emphasis on stricter reduction of CO_{2e}[1] emissions and greening the economy. This policy constitutes a Europe-wide regulatory framework that facilitates the trading of emission allowances within the EU's internal market. The EU ETS is the EU's main instrument for reducing emissions, covering approximately 40% of the total CO_{2e} emissions in the EU. The EU ETS is the cap-and-trade program for energy-intensive industries and the power generation sector, as well as aircraft operators flying within the EU. The system operates by establishing a cap on greenhouse gas emissions generated by companies within a defined geographical area, which subsequently trade emission allowances on the market. One of the EU's competencies is an annual reduction of this limit in proportion to achieving the goal of climate neutrality by 2050. This environmental policy tool encourages companies to reduce greenhouse gas emissions and ensures that emission reductions are cost-effective. It also aids in helping to improve the state of the global climate and the transition towards a sustainable economy.

The history of the EU ETS dates back to the period after the adoption of the Kyoto Protocol in 1997 (UNFCCC, 1998), when the EU began an internal process to analyse policies and measures with the aim of reducing greenhouse gas emissions. In 2000, a Green Paper on greenhouse gas emissions trading within the EU was published (European Commission, 2000), which analysed several issues related to the design of the EU ETS. The EU ETS was established by Directive 2003/87/EC, which was adopted by the European Parliament and the Council on 13 October 2003. The Directive 2003/87/EC defined the benchmarks together with the criteria required for the operation of the system and determined the framework governing national legislation (Kettner et al., 2010).

The EU ETS was, from the beginning designed to operate in phases. It has been divided into four trading phases. The first three years, from 2005 to 2007, served as a pilot phase, during which manufacturing companies had the opportunity to familiarise themselves with a new trading system. The key was to ensure the functionality of the system with regard to the achievement of the goals set in the Kyoto Protocol. The first phase only covered CO_{2e} emissions produced by electricity producers and energy-intensive industries. During the first phase, a price for Emission Unit Allowance (EUA) and free trade throughout the EU were established. In addition, the necessary infrastructure was built to monitor, report and verify actual emissions produced by covered installations. As reliable data on emissions did not exist at that time, the limits in the first phase were set on the basis of estimates. As a result, the total amount of emission allowances issued exceeded the CO_{2e} emissions produced, with allowance prices falling close to zero by the end of the first phase (Ellerman & Buchner, 2008; European Commission, 2015; Grubb et al., 2009).

Phase 2, from 2008-2012, was concurrent with the commitments of EU countries under the Kyoto Protocol. The EU also reduced the cap on allowances by 6.5% compared to 2005. The EU policy did not allow the transfer of allowances from Phase 1 (2005-2007) into Phase 2 (2008-2012). However, in the second trading period, there was a policy change, which led to the transfer of allowances between individual phases (so-called banking) in the upcoming trading periods. During the first two phases of the EU ETS, the initial allocation of allowances worked through the National allocation plans (NAPs), in which each EU country had to decide on the allocation of its allowances. During this period, most emission allowances were allocated to companies free of charge on the basis of their historical emissions (so-called grandfathering), which, however, varied across individual Member States (Abrell et al., 2011; Reyes & Gilbertson, 2010; O'Brien, 2010).

The third phase of the EU ETS started in 2013 and lasted until December 2020, featuring a significant effort to improve the harmonisation of the system across the EU. NAPs were replaced with an EU-wide cap on emissions. The target was a more ambitious reduction of total emissions within the EU, and for that reason, auctions replaced free allocation as the primary method for introducing allowances into the market. The third phase was based on significantly stricter limits that produced

[1] A CO_{2e} is a unit of measurement used to standardize the climate effects of different greenhouse gases on the basis of their global warming potential.

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higher carbon prices and included more emission reduction measures (European Commission, 2008; Communnication, 2017; Chandreyee & Velten, 2014).

Phase 4 started in 2021 and will last until 2030. This phase is characterised by significant changes and improvements in an effort to intensify the fight against climate change, as well as a reduction of the overall emission limit, which is ultimately intended to help meet the ambitious climate targets at the EU level. The rules for the current phase of the EU ETS have been implemented to raise ambitions in line with the EU's binding 2030 target of at least a 55% reduction of net greenhouse gas emissions compared to 1990 levels. In the fourth phase of the EU ETS, the Market Stability Reserve has been strengthened to stabilise carbon prices and maintain market stability (ICAP, 2023).

The aim of this paper is to investigate the impact of the EU ETS on greenhouse gas emissions in the EU 27 from 2005 to 2022. We examine the effectiveness of the system during the period 2005-2022 due to the lack of existing literature focused on all four phases, which would comprehensively evaluate the functioning of the EU ETS.

Literature review

Studies investigating the impact of the EU ETS on reduction of greenhouse gas emissions

A study by Ellerman and Buchner (2008) focuses on ex-post analysis of the EU ETS based on data from 2005-2006. For 2005, they reported a reduction of emissions between 130-200 $MtCO_{2e}$ and between 140-220 $MtCO_{2e}$ in 2006. They estimate an overallocation of emission allowances at the level of 125 million EUAs. The authors use indicators of economic activity and data on energy and emission intensity. The study concludes that there was a reduction in CO_{2e} emissions as well as the overallocation of emission allowances. However, despite the problems resulting from the launch of the EU ETS, even a slight reduction of emissions was a success. Overall, the studies highlight the positive effects of the EU ETS, specifically the EUA price, which automatically leads to the effect of reducing emissions, as well as growing GDP in relationship with the reduction of the emission intensity (Ellerman & Buchner, 2008; Anderson & Di Maria, 2011). Similarity with our study can be observed in the selected GDP indicators, indicators of the intensity of CO_{2e} emissions, and the price of emission allowances. Ellerman and Buchner (2008) examine the indicator of the overallocation of emission allowances and compare various scenarios in which they predict the development of emissions under the regulation of the EU ETS compared to the business-as-usual scenario. The study uses data on emissions from NAPs, which played a significant role in the first two trading periods, where they formed the basis for the allocation of emission allowances to installations.

Egenhofer et al. (2011) extended the study of Ellerman et al. (2010) with data from 2008-2009 and found a more significant reduction of emissions in 2008-2009 than in 2006-2007. The study evaluates CO_{2e} emissions from EU ETS sectors, the EU real GDP growth, the emission intensity, and the abatement portion. In 2006 and 2007, they observed a reduction of emission intensity by 2% and 1.9%, respectively, compared to the projected 1%, so they are able to assess that the EU ETS effectively contributed to reducing emissions. In 2008 and 2009, the emission intensity under the EU ETS regulation decreased by 3.3% and 7.4%, respectively, compared to the projected 2%. A study by Dechezleprêtre et al. (2023) uses emissions data at the installation level in four countries – France, the Netherlands, Norway and the United Kingdom with a total number of 2683 installations. They focused on regulated companies between 2005-2014, but the analysis limits to the first and second trading periods due to the expansion of the EU ETS in 2013. By applying the difference-in-difference method, the authors find that the EU ETS contributed to the reduction of carbon emissions of approximately 10% compared to companies not regulated by the EU ETS between 2005-2012. The effect of the EU ETS is greater for larger installations, in line with the claim that the transition to low-emission technologies involves high fixed costs and is capital-intensive. The study further points out that larger free allocation of emission allowances is associated with lower efforts to reduce CO_{2e} emissions. At the same time, studies suggest that the EU ETS has not only reduced emissions but also increased investment in new technologies and processes at the firm's level. This is also confirmed by an empirical study by Martin et al. (2011), which evaluates the impact of the EU ETS on CO_{2e} emissions. The purpose of their study is, among other things, to summarise and evaluate the existing ex post litera-

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ture related to the EU ETS, focusing mainly on the impact of the EU ETS on CO_{2e} emissions, economic performance, competitiveness and innovation of regulated firms in the industrial and energy sector. The study shows that, in the long run, it is desirable to stimulate innovations to help in the transition to a low-carbon economy.

Bayer and Aklin (2020) found that the EU ETS was effective despite a low emission allowance price. The study uses counterfactual emissions and estimates emissions between 8.1-11.5% lower than the sectors would have emitted without the EU ETS. Their results suggest that the EU ETS effect was greater in the second phase than in the first trading phase. A study by Anderson and Di Maria (2011) evaluates the pilot trading period from 2005-2007 and uses a dynamic panel data model to estimate the counterfactual emissions scenario for Member States. They analyse industrial emissions data to evaluate the extent of abatement and overallocation that occurred. The dependent variable in their model is the same as in our research: the overall CO_{2e} emissions. Their study estimates a total emission reduction of 247 million tons of CO_{2e} and an overallocation of 280 million EUAs. Between 2005-2007 most Member States achieved moderate emission abatement with single-digit percentage reductions, while Belgium, the Czech Republic, Ireland, Portugal and Sweden achieved double-digit percentage reductions. In absolute terms, Italy (57.1 $MtCO_{2e}$) and the Czech Republic (39.4 $MtCO_{2e}$) reduced carbon emissions the most. A recent EU ETS study by Colmer et al. (2024) examines emissions of regulated and unregulated companies before and after the introduction of the EU ETS. The authors use a matched difference-in-differences method and estimate that regulated firms reduced their emissions by an average of 14-16% compared to the control group of unregulated firms. They find no indications of outsourcing to unregulated markets or companies. On the other way, companies realised targeted investment and decreased emissions intensity. Zimmermannova et al. (2019) examine the impact of the EU ETS between 1995-2016. The study confirms a negative correlation between emission allowance price and CO_{2e} emissions reduction. It also finds a negative correlation between corporate investment, time and emission allowance price. The study confirms a positive impact of the GDP at current prices on overall CO_{2e} emissions.

However, some studies found only a small or no significant impact of the EU ETS on overall greenhouse gas emissions reduction. Authors Klemetsen et al. (2020) use data for the period 2001-2013, finding only a weak effect of the EU ETS regulation on the reduction of CO_{2e} emissions. They work with data on Norwegian plants from the Norwegian Environment Agency. The study concludes that there is no evidence of reducing emission intensity at any of the EU ETS trading phases. Calel (2020) constructs a panel of UK firms and does not confirm reductions in carbon intensity between 2005-2012. He finds that the EU ETS did not result in an improvement in companies' carbon intensity. It might be caused mainly by the already existing climate policy, which was introduced in the United Kingdom before the EU ETS. However, the study identifies that the EU ETS has a positive impact on increased low-carbon patenting and R&D expenditure among regulated firms. Another study by authors Jaraitė and Di Maria (2016) analyses the impact of the EU ETS on CO_{2e} emissions and economic performance. They use data of 5000 firms from Lithuania between 2003-2010. Through the use of a matching methodology, the study estimates the causal impact of the EU ETS participation on CO_{2e} emissions and intensity, profitability of the participating companies, and investment behaviour. The results indicate that the EU ETS participation did not result in a reduction of CO_{2e} emissions, although a slight improvement in CO_{2e} intensity was observed. Table 1 summarizes the most important studies investigating the impact of the EU ETS on the reduction of greenhouse gas emissions.

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Table 1. Studies investigating the impact of the EU ETS on the reduction of greenhouse gas emissions

Author	Data	Period	Country	Results
Ellerman and Buchner (2008)	NAPs	2005-2006	EU	reduction of emissions between 130-220 $MtCO_{2e}$
Anderson and Di Maria (2011)	Eurostat	2005-2007	EU	emission reduction of 247 $MtCO_{2e}$
Egenhofer et al. (2011)	Eurostat	2006-2009	EU	reduction of emission intensity by 2% in 2006, by 1.9% in 2007, by 3.3% in 2008, and by 7.4% in 2009
Dechezleprêtre et al. (2023)	Orbis, EUTL	2005-2014	FR, NL, NO, UK	EU ETS reduced carbon emissions by around 10%
Bayer and Aklin (2020)	EUTL, UNFCCC	2008-2016	EU	emissions between 8.1-11.5% lower
Colmer et al. (2024)	ADEME, EACEI, INSEE	1996-2012	FR	regulated firms reduced their emissions by an average of 14-16%
Zimmermanova et al. (2019)	Eurostat, OTE, EEX	2005-2016	EU	EU ETS contributed to the reduction of greenhouse gas emissions
Klemetsen et al. (2020)	Norwegian Environment Agency	2001-2013	NO	weak effect on the reduction of CO2e emissions
Jaraitė and Di Maria (2016)	Micro data	2003-2010	LT	no reduction of CO_{2e} emissions, but a slight improvement in CO_{2e} intensity
Calel (2020)	Micro data	2005-2012	UK	EU ETS did not result in an improvement in companies' carbon intensity

Studies assessing the impact of EUA price on overall emissions

A study by Delarue et al. (2008), which examines the first and second trading periods, estimated that carbon price signals cut emissions in the energy sector by 88 $MtCO_{2e}$ in 2005. They used an electricity generation simulation model that indicate a statistically significant dependence between reducing emissions and the EUA auction price. The EU ETS has the potential to reduce emissions by up to 300 $MtCO_{2e}$ per year at a sufficiently high EUA price. Kettner et al. (2010) investigate EUA price volatility in the first and second phases of the EU ETS and predict the development in the post-Kyoto phase for the period 2013-2020. The study comprehensively evaluates the situation in all EU countries while selecting emission-intensive sectors. To investigate the stringency of the EU ETS, it uses four indicators, i.e. gross short, gross long, net short, and net long positions, as the differences between allocated EUAs and actual emissions of installations. The study concludes that carbon prices were influenced, among other things, by institutional factors that lower the overall emission cap and thus increase the EUA price. Carbon prices are intended to act as a price signal for investment; their high volatility makes them an unreliable basis for decision-making. This argument supports incorporating additional price-stabilizing mechanisms into the EU ETS. An ex-post study by Zimmermannova et al. (2015) from the third trading period analysed the key EU ETS sector – the sector of combustion processes in the Czech Republic. An empirical research and Mamdani fuzzy rule-based system were used. The study found that the behaviour of the Czech companies does not meet policy-makers' expectations. There was a weak motivation within the combustion processes sector in the Czech companies to trade with emission allowances. The study also compares the price of emission allowances with regulation in the form of an environmental tax, finding that the allocated allowances had similar effects on reducing emissions as an environmental tax. Bayer and Aklin (2020) assess the EU ETS and focus on its efficiency despite low EUA prices. They use an original sectoral emissions dataset and estimate counterfactual CO_{2e} emissions. The study finds that the EU ETS saved cumulatively approximately 1.2 billion tons of CO_{2e} in the period 2008-2016, and it accounts for nearly half of the EU commitment under the Kyoto Protocol. Also, possible future increases in the price of emission permits can motivate companies to reduce emissions despite the currently low price of emission permits. Higher emission reductions were achieved in sectors covered under the EU ETS. In addition

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to the impact of carbon prices on emissions, a study by Zimmermannova et al. (2019) examines other variables. The study evaluates the effect of the price of emission allowances in the auction on overall emissions, concluding that a unit increase in the price of emission allowances is associated with a decrease in overall emissions of approximately 64,455 units. The study evaluates the second and third trading periods and emphasises that the EUA price has different influences in different phases, while this variable proved to be statistically insignificant when evaluating the entire period of the EU ETS. Table 2 provides a summary of studies assessing the impact of EUA price on overall emissions.

Table 2. Studies assessing the impact of EUA price on overall emissions

Author	Data	Period	Country	Impact on overall emissions
Delarue et al. (2008)	NAPs	2005-2012	EU	yes
Kettner et al. (2010)	CITL, NAPs	2005-2008	EU	yes
Zimmermannova et al. (2015)	EEX, sectoral data	2013	CZ	yes
Zimmermannova et al. (2019)	Eurostat, OTE, EEX	2005-2016	EU	yes
Bayer and Aklin (2020)	EUTL, UNFCCC	2008-2016	EU	yes

Studies examining the impact of the EU ETS on economic activity

There are many studies examining the impact of the EU ETS on economic activity. The literature relies on the approach of comparing companies regulated by the EU ETS and companies that are not regulated by the EU ETS. The main difference is that economic performance indicators are usually monitored at the company level, and emissions are monitored at the installation level (Dechezleprêtre et al., 2023). In general, the introduction of the EU ETS raised concerns across sectors, with many models predicting that the evolution of the EUA price around 15-32 EUR/MtCO_{2e} would rather affect energy-intensive sectors, including cement, aluminium, paper and chemical industries (Laing et al., 2014; Sato et al., 2015). A study by Sato et al. (2015) investigates sectors during the third trading period in the EU, UK, and Germany, assessing the risk of carbon leakage under the influence of the EU ETS. However, it cannot clearly identify the risk of carbon leakage due to the large number of factors that need to be considered when assessing the risk of carbon leakage. Exposure risk to carbon leakage differs for the same sector across Member States.

Early studies (Abrell et al., 2011; Commins et al., 2011) carried out to evaluate the impact of the EU ETS on the economic performance of companies show shortcomings because they compared firms that did not belong to the same industry. Also, studies failed to control for time-varying and sector-specific factors. Commins et al. (2011) investigated the impact of energy taxes and the EU ETS on firms in Europe from 1996-2007. Firm-level micro-data were used to analyse the impact of environmental policies on companies across different sectors. The study examines various aspects of behaviour and performance, including profitability, investment behaviour, employment levels, and total factor productivity. It concludes that energy taxes increased returns to capital and boosted total factor productivity but reduced employment with an ambiguous effect on investment. Also, large sectoral differences are observed, with some industries losing productivity and profitability due to increased energy taxes while other firms benefit from such policies. Abrell et al. (2011) examine the impact of the EU ETS at the firm level. Panel data on the emissions and performance of approximately 2000 European firms in 2005-2008 were used to analyse the effectiveness of the EU ETS. The results indicate that the transition from the first phase to the second phase affected the emission reductions realised by firms. Additionally, the initial allocation significantly influenced emission reduction. This calls into question the applicability of Coase's theorem to the EU ETS, which posits that the initial allocation of emission allowances does not affect the post-trading distribution of marketable pollution permits. Between 2005-2008, the EU ETS had a moderate impact on the performance of participating companies. A full transition to an auction system could significantly help reduce emissions, but at the same time, it could negatively affect the profits of participating companies.

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Drawing from interviews with nearly 800 manufacturing firms across six European countries, a study by Martin et al. (2011) examines the impact of the EU ETS on climate change related measures and clean innovation during the first and second trading periods. The authors found that the majority of the companies adopted measures to reduce greenhouse gas emissions related to energy saving and thus reduced greenhouse gas emissions from their machinery and core processes. The reason is that companies anticipate that carbon prices will be significantly higher in the future compared to current levels in the EU ETS. The study concludes that there is a significant positive correlation between firms' expectations regarding the future stringency of their cap and clean innovation. Chan et al. (2013) investigated firms regulated under the EU ETS and firms not regulated under the EU ETS in the same sector. They cover the steel, cement and power production industries over the period 2001-2009. The study found that the EU ETS had no impact on economic indicators in the iron, steel and cement industries. Further, the study's findings indicate no impact on job losses, industry competitiveness, and carbon leakage. A study by Colmer et al. (2024) investigates the impact of the EU ETS on CO_{2e} emissions as well as on economic activity and finds that the EU ETS had no detectable effect on the economic performance of firms measured by the number of employees and value added. It estimates that firms regulated under the EU ETS increased capital investment during the first trading phase by 8.3% and during the second trading phase by 10.5%. During the second trading phase, regulated firms reduced CO_{2e} emissions by 17.4%. Table 3 summarises studies examining the impact of the EU ETS on economic activity.

Table 3. Studies examining the impact of the EU ETS on economic activity

Author	Data	Period	Country	Impact on economic activity
Sato et al. (2015)	Office for National Statistics (UK), Federal Statistical Office of Germany	2013-2020	UK, DE, EU	ambiguous
Commins et al. (2011)	company level micro-data	1996-2007	EU	ambiguous
Abrell et al. (2011)	Amadeus, CITL	2005-2008	EU	positive
Martin et al. (2011)	interviews	2001-2009	BE, FR, DE, HU, PL, UK	positive
Chan et al. (2013)	Amadeus, CITL	2001-2009	EU	positive
Colmer et al. (2024)	ADEME, EACEI, INSEE	1996-2012	FR	positive

Data and methodology

We set a research question: Was the EU ETS effective in reducing overall CO_{2e} emissions in the EU27 in the period 2005-2022?

As part of the regression analysis, we estimated linear regression models using the ordinary least squares (OLS) method. We obtained data from various sources. We use annual data on overall emissions of CO2 equivalent (CO_{2e}) in metric tons from the European Union Transaction Log (EUTL) database. From the Eurostat database, we extract data on the average annual GDP and data on the total and corporate investment in the EU27 countries in millions of EUR. The average annual price of emission allowances for the period 2005-2022 is obtained from the Energy Regulatory Office in the Czech Republic. The annual average price of such an emission allowance represents the weighted average closing price on the European Energy Exchange. By using the average annual price of emission allowances on the market, we are able to exclude the volatility that can be observed when using daily stock closing prices. In total, we include five control variables in our regression model: average annual GDP in the EU27, total investment in the EU27, corporate investment in the EU27, average annual price of emission allowance, and time. The control variables are chosen with regard to the expected impact on

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overall CO_{2e} emissions. Our research extends the research of Zimmermannova et al. (2019) by using the latest data available to analyse the EU ETS throughout all four phases from 2005 to 2022. We focus on the average EUA market price, which proved to be less volatile and, therefore, more reliable for modelling in comparison to the average EUA auction price.

The first control variable in this study is the average annual GDP in the EU27 countries, which provides insight into the current economic development of a country. According to this indicator, we can determine periods of expansion or recession, which indicate the intensity of industrial production of emission-intensive sectors. In times of recession, we expect a decrease in overall greenhouse gas emissions as a result of reduced industrial production, on the other side, in times of expansion, we expect growth in production and a related increase in overall greenhouse gas emissions (Samuelson & Nordhaus, 2010) .

The second control variable in the model is the average annual total investment as a component of GDP in the EU27 countries. The variable represents the formation of gross fixed capital by the government sector, the business sector and the household sector. It is defined as the acquisition of produced assets, including the production of such assets by producers for their own use, minus disposals. The expected impact on the dependent variable is negative due to the predicted decrease in CO_{2e} emissions with the growth of investment (OECD, 2024).

The third control variable is the average annual corporate investment as a component of GDP in the EU27 countries. In accordance with Porter's hypothesis, we assume that companies can benefit from the introduction of environmental policies when they move to less emission-intensive and cleaner technologies. Green investment can contribute to the productivity of companies and lead to higher competitiveness (Colmer et al., 2024; van Leeuwen & Mohnen, 2017).

The fourth control variable is the average annual EUA market price. The average EUA auction price and the average EUA market price differ due to their nature. While the average EUA auction price is more volatile, the average EUA market price provides more reliable data for modelling. Several environmental economists identified the EUA market price as a relevant tool for determining overall CO_{2e} reduction (Delarue et al., 2008; Ellerman & Buchner, 2008; Kettner et al., 2010).

The fifth control variable is time and represents the period 2005-2022, showing a trend of gradual reduction of CO_{2e} emissions within all countries of the European Union. This development is in line with many environmental initiatives and policies that have been adopted at the EU level and in individual Member States during this period.

Results of the research

Descriptive statistics

Table 4 provides descriptive statistics information. The data show that CO_{2e} emissions in the EU27 reached their maximum level of 4.196 billion metric tons in 2005, while the lowest recorded value was 3.052 billion metric tons in 2020. The data further indicate that the CO_{2e} emissions decreased gradually, which could be attributed to ambitious commitments to address climate change challenges at the EU level. The annual GDP in the EU27 reached its maximum in 2022 at approximately 15,910 trillion EUR. The variables total investments and corporate investments in the EU27 reached their maximum in 2022, with their value at 3.571 trillion and 1.966 trillion EUR, respectively. The average of total investments was at the level of 2.599 trillion EUR, while the average of corporate investments was at the level of 1.547 trillion EUR. The average EUA market price reached its maximum value at 80.85 EUR per emission allowance, while the annual minimum was 1.50 EUR in 2005. During the period under review, price fluctuations were recorded and pushed the EUA price close to zero during the first phase in 2007. On average, the price was 18.44 EUR per emission allowance.

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Table 4. Descriptive statistics

	MAX	MIN	Average
CO_{2e} emissions (bn. $MtCO_{2e}$)	4.196	3.052	3.631
GDP (tn. EUR)	15.91	9.561	12.14
Total investment (tn. EUR)	3.571	2.101	2.599
Corporate investment (tn. EUR)	1.966	1.305	1.547
EUA price (EUR)	80.85	1.50	18.44

Correlation analysis

The results of the correlation analysis using Pearson correlation (Table 5) show that the variable EUA price is moderately strongly negatively correlated with the CO_{2e} emissions variable (-0.4523). From the correlation matrix, we further observe a strong negative correlation of the CO_{2e} emissions variable with time (-0.9492) and with the GDP variable (-0.8597). The GDP variable has a strong positive correlation with total investment (0.9444) and corporate investment (0.8994). Total investment and corporate investment have a very strong positive correlation with time, indicating that investment increases over time.

Table 5. Correlation analysis

	CO_{2e} emissions	EUA price	GDP	Total investment	Corporate investment	Time
CO_{2e} emissions	1					
EUA price	-0.4523	1				
GDP	-0.8597	0.6773	1			
Total investment	-0.6977	0.7756	0.9444	1		
Corporate investment	-0.7104	0.7701	0.8994	0.9662	1	
Time	-0.9492	0.5223	0.9621	0.8399	0.8071	1

We examine the relationship between individual variables through regression analysis. To do so, we estimate two models using the OLS method, with Model 1 including all variables and Model 2 omitting the insignificant GDP variable.

Regression analysis: Model 1

Table 6 shows the results of Model 1 regression analysis. We use the OLS method to estimate model parameters. The dependent variable is the level of overall emissions of CO2 equivalent in metric tons ($MtCO_{2e}$) in the EU27 countries. The independent variables are the average annual GDP in the EU27 in millions of EUR (X1), average annual total investment in the EU27 in millions of EUR (X2), average annual corporate investment in the EU27 in millions of EUR (X3), average annual EUA market price in EUR (X4) and time (X5).

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Table 6. Results of regression analysis: Model 1

	Coefficient	Std. Error	t-ratio	p-value
const	2.23074e+08	3.23750e+07	6.890	<0.0001 ***
X1	0.119002	0.0846225	1.406	0.1850
X2	0.695234	0.199284	3.489	0.0045 ***
X3	−0.869795	0.222892	−3.902	0.0021 ***
X4	−3830.07	1276.41	−3.001	0.0111 **
X5	−109897	16441.0	−6.684	<0.0001 ***
Mean dependent var	3630910	S.D. dependent var		354239.2
Sum squared resid	5.63e+10	S.E. of regression		68511.79
R-squared	0.973596	Adjusted R-squared		0.962594
F (4. 26)	248.8501	P-value (F)		1.10e-11
Log-likelihood	−222.3174	Akaike criterion		456.6348
Schwarz criterion	461.9770	Hannan-Quinn		457.3714
rho	−0.323316	Durbin-Watson		2.344304
		dL; dU		0.71; 2.06
White test LM	7.30101	CV		18.307

Note: *p<0.05; **p<0.01; *** p<0.001.

The results from the regression analysis confirm that the EU ETS contributes to the reduction of CO_{2e} emissions in the EU27 countries, and therefore, we assess that the system is effective. Only the GDP variable with p-value of 0.1850 is statistically insignificant. The other variables in Model 1 are statistically significant, and we will include them in the second model, which will also be estimated using the OLS method.

Regression analysis: Model 2

Model 2 (Table 7), which examines the impact of total investment, corporate investment, EUA price, and time on overall CO_{2e} emissions, is statistically significant.

We observe a positive effect of total investment, based on the model, an increase in total investment is positively associated with an increase in CO_{2e} emissions. However, we cannot apply the same interpretation to the corporate investment. If corporate investment increases, total CO_{2e} emissions will decrease, which is consistent with the model's expectation. This is consistent with Porter's hypothesis, which argues that well-designed environmental regulation can boost firms' competitiveness. Based on the regression analysis in Model 2, we confirm that the rate of decrease in emissions is more significant if the EUA price increases. We also confirm a decrease in emissions over time.

Table 7. Results of regression analysis: Model 2

	Coefficient	Std. Error	t-ratio	p-value
const	1.78841e+08	7.75983e+06	23.05	<0.0001 ***
X2	0.976196	0.144017	6.778	<0.0001 ***
X3	−1.05220	0.238924	−4.404	0.0007 ***
X4	−3161.98	1085.02	−2.914	0.0121 **
X5	−87440.4	3922.27	−22.29	<0.0001 ***
Mean dependent var	3630910	S.D. dependent var		354239.2
Sum squared resid	6.19e+10	S.E. of regression		69004.24
R-squared	0.970983	Adjusted R-squared		0.962055
F (4. 26)	332.0555	P-value (F)		6.07e-13
Log-likelihood	−223.1667	Akaike criterion		456.3334
Schwarz criterion	460.7853	Hannan-Quinn		456.9473
rho	−0.428350	Durbin-Watson		2.688614
		dL; dU		0.82; 1.87
White test LM	15.6116	CV		23.6848

Note: *p<0.05; **p<0.01; *** p<0.001.

Discussion

We analysed existing studies investigating the impact of the EU ETS, and we divided them into three groups: a) studies investigating the impact of the EU ETS on the reduction of greenhouse gas emissions; b) studies assessing the impact of EUA price on overall emissions; and c) studies examining the impact of the EU ETS on economic activity.

Our research shows that the EU ETS has contributed significantly to the reduction of total emissions in the EU since its introduction in 2005. Also, we find strong evidence that total investment, corporate investment, and price of emission allowance have an impact on the CO_{2e} emissions in the EU27. We compared our findings with the results of studies focused on the impact of the EU ETS on emissions reduction and economic activity.

Most of the reviewed studies confirmed the conclusions of our research as they evaluated the EU ETS as effective (Abrell et al., 2011; Martin et al., 2011; Chan et al., 2013; Colmer et al., 2024; Ellerman & Buchner, 2008; Anderson & Di Maria, 2011; Egenhofer et al., 2011; Dechezleprêtre et al., 2023; Bayer & Aklin, 2020; Zimmermanova et al., 2019). However, some studies could not definitively confirm or deny the effectiveness of the EU ETS. Commins et al. (2011) examine the impact of energy taxes and the EU ETS on firms in Europe in 1996-2007. They use firm-level micro-data to analyse the impact of environmental policies on companies across different sectors. Their study examines profitability, investment behaviour, employment levels, and total factor productivity. Commins et al. (2011) conclude that energy taxes increased returns to capital and boosted total factor productivity. However, they reduced employment with an ambiguous effect on investment. Some industries experienced decreased productivity and profitability due to increased energy taxes, while other firms benefited from such policies. Sato et al. (2015) investigate sectors during the third trading period in the EU, UK and Germany, assessing the risk of carbon leakage under the influence of the EU ETS. However, their study cannot clearly identify the risk of carbon leakage due to the large number of factors that need to be considered when assessing the risk of carbon leakage. Exposure risk to carbon leakage differs for the same sector across Member States due to many differences in technologies, production and recycling processes, and the quality of the data.

Other studies have noted significant improvements in investment in innovation within businesses but only a weak or no effect on reducing the intensity of emissions (Calel, 2020; Klemetsen et al., 2020; Jaraitė & Di Maria, 2016). Also, Jaraitė and Di Maria (2016) and Klemetsen et al. (2020) did not confirm the effectiveness of the EU ETS due to insufficient evidence of the reduction of CO_{2e} emissions. Klemetsen et al. (2020) find only a weak effect of the EU ETS regulation on the reduction of CO_{2e} emissions. Their study uses data on Norwegian plants (2001-2013) and finds that there is no evidence of reducing emission intensity at any of the EU ETS trading phases. Calel (2020) constructs a panel of UK firms and does not confirm reductions in carbon intensity between 2005-2012. He concludes that the EU ETS did not result in an improvement in companies' carbon intensity. However, his study identifies that the EU ETS has a positive impact on increased low-carbon patenting and R&D expenditure among regulated firms. Another study by Jaraitė and Di Maria (2016) analyses the impact of the EU ETS on CO_{2e} emissions and economic performance using data from 5000 firms from Lithuania between 2003-2010. Their results indicate that the EU ETS participation did not result in a reduction of CO_{2e} emissions, although a slight improvement in CO_{2e} intensity was observed.

Subsequently, we analysed studies evaluating the impact of the EUA price on overall CO_{2e} emissions as a decisive factor in the effectiveness of the EU ETS and our conclusion is in line with the findings of other available studies. The results from studies (Bayer & Aklin, 2020; Delarue et al., 2008; Kettner et al., 2010; Zimmermanova et al., 2015; Zimmermanova et al., 2019) assessing the impact of EUA price on overall emissions are unambiguous and positive. Different authors focus on different trading periods. Delarue et al. (2008) and Kettner et al. (2010) investigate the first and second phase of the EU ETS, Bayer and Aklin (2020) and Zimmermanova et al. (2019) examine first, second and third period, and Zimmermanova et al. (2015) focus on third phase of the EU ETS. We use the latest data available and our research examines all four trading periods from 2005 to 2022, and we can confirm that EUA price has a positive impact on overall CO_{2e} emissions.

Conclusion

At the beginning of the research, we set a research question: Was the EU ETS effective in reducing the amount of CO_{2e} emissions in the EU27 during the period 2005-2022? Based on the results of Model 2, we can conclude that the EU ETS has contributed to the reduction of total emissions by 42.8% in the EU since its introduction in 2005. We applied two regression models and can confirm that total investment, corporate investment, price of emission allowance, and time are statistically significant and have an impact on the CO_{2e} emissions in the EU27. Our findings suggest that the EU ETS has become an effective tool in the transition to a low-carbon future within the sectors included in the system. We conclude that the EU ETS has also provided a financially effective tool for eliminating CO_{2e}, which is considered the main driver of climate change. However, we recognise the need to link the EU ETS with other emissions trading systems outside the European Union as a guarantee to achieve carbon neutrality by 2050.

We analysed existing studies investigating the impact of the EU ETS, and we recommend: a) providing businesses with various support schemes to facilitate the transition to low-emission production; b) setting ambitious emissions reduction targets; c) continuously strengthening and expanding the EU ETS to new sectors; and d) regularly assessing the EU ETS with regard to the EU's competitiveness to effectively achieve the ambitious target of carbon neutrality by 2050. Based on our research findings, we conclude that the EU ETS has the potential to reduce emissions, and we assume that it will continue to be successful in the future with regular evaluation and monitoring of its functioning, driven by the low-carbon transition of emission-intensive and energy-intensive industries in the EU.

To be more specific, we provide more detailed proposals for solutions. One of the problems within the EU ETS is the volatility of emission allowance prices, as well as the price itself, which motivates companies in emission-intensive sectors to invest and make technological improvements to reduce CO_{2e} emissions. Taking into account the possible sharp increase in the price of emission allowances, we recommend extending the Market Stability Reserve of the EU ETS, which serves as a solution to the surplus of emission allowances. We propose to extend the validity of the Market Stability Reserve until 2050 as a long-term guarantee of protection against unexpected external factors that cause price volatility, which will make the carbon market more resilient. In the coming period, it will be crucial to support companies and sectors covered by the EU ETS through incentives and subsidies to invest in environmentally sustainable technologies. It should reduce their emissions without jeop-

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ardising profitability, employment or increasing marginal production costs. The measures should lead to a reduction in carbon intensity and higher trading activity in the EU ETS and should be implemented, regularly monitored and evaluated at European and national levels. However, with the increasing efficiency of the EU ETS, we suggest that a more rapid decrease in total number of emission allowances is needed to be able to meet set targets. Several new sectors will be added to the system, for example, buildings, road transport and municipal waste incineration what will have a very positive effect on overall emissions. So, we recommend to continuously including new sectors in the EU ETS.

This study, however, has several limitations. We investigate the situation in the EU27, but there are significant differences between Member States in the degree of energy intensiveness. A future study could focus on specific countries, groups of countries, and emission- and energy-intensive industries throughout all four phases from 2005 to 2022. We suggest developing more accurate methods for measuring and reporting CO_{2e} emissions, such as continuous emissions monitoring systems that measure CO_{2e} emissions and other greenhouse gas emissions from industrial combustions and exhaust directly at the measurement location with high accuracy. It would be beneficial to combine data from multiple sources, including satellite imagery, sensor networks, and weather data, and to use machine learning algorithms to improve the accuracy of emission estimates and forecasts. In the future, we would consider tailoring emissions measurement methods to specific sectors such as agriculture, energy production, and transportation, considering the unique characteristics and sources of emissions in each sector.

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The contribution of the authors

Conceptualisation, R.K. and S.H.; literature review, R.K. and S.H.; methodology, S.H.; formal analysis, R.K. and S.H.; writing, R.K. and S.H.; conclusions and discussion, R.K. and S.H.

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