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The effectiveness of the European Union Emissions Trading System in reducing country-sector greenhouse gas emissions.

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Abstract

This research investigates the impact of environmental regulation in decreasing greenhouse gas emissions. The regulation that this research assesses is the European Union Emissions Trading System (EU ETS). It was first implemented in 2005 and is currently in its fourth stage which lasts from 2021 to 2030. Through the use of 205 country-sector combinations between the years 1990 and 2021, this research aims to explore the effectiveness of the EU ETS in reducing country-sector emissions by applying a difference-in-difference approach. The research compares the emissions in country-sectors within the EU ETS to the country-sectors excluded from the EU ETS policy at three different time periods: 2007, 2012, and 2020. These time periods reflect the last intervention period of the first three stages of EU ETS. The expectation is that the EU ETS would have negatively impacted the emissions, that is, reduce the number of country-sector emissions at each stage of this Policy. The first set of regression results, however, showed statistically insignificant values. Nonetheless, the second set of results showed that the energy sector is the largest contributor to emissions reductions.

Contents

1. Introduction

The climate crisis faced by the world today is record-breaking. Rising temperatures, natural disasters, food and water insecurity, air pollution and land contamination have all fueled environmental degradation and have led to a climate emergency, threatening humanity, and the planet. One cause of this crisis is greenhouse gas emissions. The greenhouse gases that blanket the Earth have led to the world warming faster than ever before, disrupting the balance of nature. These emissions are the largest contributor to global climate change accounting for almost 90% of all carbon dioxide emissions (United Nations, n.d.). In order to tackle this emergency, world leaders have implemented policies to reduce the damage to the environment. The European Union Emissions Trading System (EU ETS or Policy) is a notable initiative designed to combat climate change and mitigate greenhouse gas emissions. In addition to the 27 countries comprising of the EU, the Policy also includes Iceland, Liechtenstein, and Norway. The EU ETS limits emissions from energy, manufacturing, and aircraft operations of these countries, thus covering approximately 40% of the EU's greenhouse gas emissions (*EU Emissions Trading System*, n.d.). This research will explore how the EU ETS functions and its role in combating climate change through the reduction in emissions.

The gases covered under the EU ETS include carbon dioxide emissions from electricity and heat generation, energy-intensive industries such as oil refineries or production of metals, and aviation within the European Economic Area (EEA). Furthermore, nitrogen oxide released during the production of acids and perfluorocarbons from the production of aluminum are also included in the Policy. These gases are combined into four different sectors: energy, industrial process and product use, agriculture, and waste. All firms operating in these sectors are required to participate in the EU ETS. However, there is an exception that in some sectors, only those companies above a certain size participate, and the others are exempted (*EU Emissions Trading System*, n.d.). The EU ETS works based on the principle of cap-and-trade for carbon emissions by relevant businesses. The cap limits the number of emissions by gradually being reduced over time. Within this cap, business owners can trade emission allowances. Therefore, the increasing prices of these allowances incentivize emitters to reduce their emissions and instead invest in lower carbon technologies.

The need for a policy instrument to meet the targets of the 1997 Kyoto Protocol led to the implementation of the first stage of the EU ETS which ran from 2005 to 2007. It is now in its fourth stage, which runs between 2021 and 2030. The framework of the Policy is regularly revised to meet the overall EU climate objectives. Stage 1 succeeded in establishing a price for carbon, allowed free trade emission allowances across the EU, and developed the infrastructure needed to monitor, report, and verify the number of emissions. One issue encountered in the first stage was that the cap on emissions was set based on estimates. The actual emissions were much lower than these estimates, leading to an easier availability of allowances. With a much larger supply of allowances than demand, the price of allowances eventually fell to zero. Stage 2, which was implemented between 2008 and 2012, used data on actual emissions generated in stage 1, thus understanding that the cap on the emissions need to be reduced. However, the 2008 financial crisis led to reductions in emissions that were much larger than expected. Hence, this again led to a large surplus of allowances and subsequently lower prices. Finally, stage 3 ran from 2013 to 2020 where the system changed considerably compared to the previous two stages (*EU Emissions Trading System*, n.d.). For these reasons, the goal of this research is to find the effectiveness of the EU ETS in reducing greenhouse gas emissions by determining the magnitude of emission reductions after the implementation of the Policy in each of the first three stages. Thus, the research question is:

"To what extent was the European Union Emissions Trading System effective in reducing country-sector greenhouse gas emissions in its first three stages?"

The extent of the reduction in emissions can be investigated through the following hypothesis:

Null hypothesis: there is no effect of the EU ETS on the number of emissions per 1,000,000 inhabitants for the countries and sectors that are subject to this Policy in each of its stages.

Alternate hypothesis: the EU ETS aided in reducing the number of emissions per 1,000,000 inhabitants for those countries and sectors included in this Policy for each of its stages.

Much of the research conducted on the effectiveness of the EU ETS policy has focused on the first and second stages of the total four stages that are in place. The research on this topic has been undertaken through various analytical methodologies, such as the synthetic control method, fixed effects method, or the difference-in-difference method. For example, Bayer and Aklin (2020) incorporated the synthetic control approach to find that the EU ETS policy has been effective in reducing emissions. To do this, they used the number of emissions from the different sectors within the EU ETS and compared it to the emissions from the non-EU ETS sectors. On a more firm-level analysis, Abrell et al (2021) used the fixed effects estimate to identify factors that influence firms' decisions within the EU ETS policy. They did this by using the number of allowances bought and sold by firms as a dependent variable while controlling for company characteristics as fixed effects. Several studies that use the difference-in-difference methodology have applied it to firm level data. For instance, Löschel et al (2019) applied this method to find the impact of the EU ETS on efficiency and economic performance of German manufacturing firms and argued that the Policy can be effective in reducing greenhouse gas emissions without negatively impacting economic performance. Their results defend this argument. Löfgren et al (2013) also employ this approach in their research of the effect of the EU ETS on company investments and find that the system was able to reduce greenhouse gas emissions but lacked in incentivising to make investments in low-carbon technologies. Given this, the following research will contribute to the existing literature by implementing the difference-in-difference approach to country-sector level data and analysing the effectiveness of this emissions reducing Policy on the three stages running from 2005 to 2020.

Furthermore, the EU ETS has an impact on the most important levels of society: the country, the government, and businesses. Therefore, this research can also be seen as socially relevant. If this Policy is deemed successful, it can be applied in other, non-EU countries, and can possibly have the reduction in greenhouse gas emissions required to meet the climate goals set by the governments around the world.

In order to answer the research question, data on the number of greenhouse gas emissions by sector in 30 countries included in the EU ETS policy is compared to the greenhouse gas emissions in 11 countries that are not included in this Policy by the means of a difference-in-difference approach. The interaction between the intervention periods, being subject to the EU ETS, and sectors included in the EU ETS will identify the treatment effect. Using this method, the main results were found to be insignificant in explaining the effect of the EU ETS on country-sector greenhouse gas emissions. However, it was also found that the energy sector contributed most towards the emissions reduction.

The remainder of the paper is structured as follows. Section 2 discusses the related literature to provide a deeper understanding of the EU ETS policy. Section 3 details the data and empirical methodology used for analysis. This is followed by a presentation and discussion of the results in Section 4. Subsequently, Section 5 conducts robustness checks to ensure the validity and reliability of the difference-in-difference approach. Finally, a conclusion and discussion are provided in Section 6.

2. Related Literature

Research on the overall effect of the EU ETS in reducing emissions is limited. The research tends to focus on specific firms or sectors that are affected by this Policy. However, one paper that tries to find the overall effect is authored by Bayer and Aklin (2020). They estimated the effect of the EU ETS policy on carbon dioxide emissions through the use of a generalised synthetic control approach. They used data on emissions generated within each sector included in the EU ETS for the first two stages (2005 to 2012) of the Policy. Despite criticism that the EU ETS has failed to achieve significant reductions in emissions due to low carbon prices, they find evidence that the Policy has been effective. Their results state an emission reduction of 8.1% and 11.5% in the years 2005 and 2008, respectively. Similarly, Laing et al (2013) evaluate the effectiveness of the EU ETS and find that the Policy reduced emissions by approximately 200 million tonnes. However, Laing et al (2013) mention that the EU ETS only contributes to 45% of reductions while other complementary policies account for the remaining 55%. One characteristic of the research conducted here that is different from Bayer and Aklin (2020) is that the difference-in-difference approach compares data on number of emissions generated in countries implementing the EU ETS to the number of emissions generated in countries without the EU ETS program using actual, verified data. On the other hand, Bayer and Aklin (2020) predict the number of emissions had there not been the EU ETS policy "from observable emissions in those sectors that are not covered under the EU ETS" (Bayer & Aklin, 2020, p. 8806). As a result, differences in data arise as this research uses number of emissions that are measured and reported to credible sources while Bayer and Aklin (2020) predict the values which could cause inaccuracies in data.

Clò (2008) undertook a similar analysis as Bayer and Aklin (2020) where the effectiveness of the EU ETS in achieving the Kyoto Protocol target of reducing greenhouse gases was examined. The focus was on the cap stringency, or the level of emissions allowed under the Policy, and its impact on emissions reductions. He found that the initial cap stringency of the EU ETS was not strict enough to achieve the Kyoto Protocol target. However, this was adjusted in subsequent stages of the Policy, resulting in a greater reduction in emissions. Clò (2008) argues that the EU ETS was effective in achieving emissions reductions because of this adjustment. However, he also highlights the importance of complementary policies in achieving emissions reductions. The author notes that the EU ETS was not the only policy in place to reduce emissions, and that other policies, such as renewable energy targets, played a significant role in achieving the Kyoto target. Clò's (2008) research is relevant in this analysis since it tries to verify if there indeed were significant reductions in emissions.

Similarly, Abrell et al (2011) assessed the impact of the EU ETS with a specific focus on data from 2,500 firms between the years 2005 to 2008. The authors find that the EU ETS had limited impact on reducing emissions in the short term as the firms had access to allowances at lower prices and continue emitting at similar levels. However, in the long term, firms make investments in cleaner technologies to decrease their emissions. On the contrary, Löfgren et al (2013) argue that the EU ETS has had a limited impact on company investments in low-carbon technologies. Their difference-in-difference regression suggested that although the EU ETS has been successful in reducing greenhouse gas emissions, they contend that it has not been effective in encouraging investments in low-carbon technologies. Firms subject to the EU ETS did not invest significantly more in carbon-reducing technologies than those not subject to it, suggesting that the EU ETS is not providing enough incentives to firms to reduce their emissions.

Studying a different sector covered by the EU ETS, Heiaas (2021) focuses on the effectiveness of the Policy in the aviation industry in reducing carbon emissions by using the synthetic control method. The study analyses data from the period of 2012 to 2019, during which the EU ETS was in effect for flights within the EEA. Using jet fuel consumption as a proxy for emissions, the analysis finds that the EU ETS has had a limited impact on reducing emissions from aviation. Specifically, on average the EU ETS led to a 10% increase in jet fuel consumption compared to a scenario where the EU ETS is not applied. Heiaas (2021) concludes by stating that the EU ETS has not yet achieved significant emissions reductions in the aviation sector. Other complementary policies such as a tax on aviation fuel may be necessary to achieve more significant emission reductions from air travel.

Since the EU ETS aims to reduce carbon emissions of businesses, it is possible that economic performance is also affected. There are some researchers who explore this. Dechezleprêtre et al (2023) investigated the impact of the EU ETS on carbon emissions and economic performance of regulated companies between 2005 to 2014. Their main argument is that the EU ETS has been effective in reducing carbon emissions without significantly harming economic performance. The authors found that the EU ETS was able to significantly reduce emissions within the regulated installations by 3.8% compared to the non-regulated installations. Although the regulated firms noticed a slight negative impact on their profits in the short-term, this effect disappeared in the long-term. The authors found no significant impact of the Policy on employment or investment decisions, thus providing evidence of the EU ETS being effective in reducing carbon emissions without significantly impacting the economic outcomes. Similarly, Löschel et al (2019) analysed the effects of the EU ETS on the economic performance of German manufacturing firms and argue that the EU ETS can be an effective tool in reducing greenhouse gas emissions without negatively impacting economic performance.

3. Data and Empirical Methodology

3.1. Data

3.1.1. Emissions data by EU ETS sectors

The data on greenhouse gas emissions for the four sectors included in the EU ETS were collected from the United Nations Framework Convention on Climate Change (UNFCCC) which collects information on greenhouse gas emissions and helps track the progress towards emission reduction targets. The four sectors covered under the EU ETS are energy, industrial process and product use, agriculture, and waste. From this database, greenhouse gas data for 30 countries included in the Policy and for 11 that are not included in the EU ETS for the years 1990 to 2021 were collected. The countries subject to the EU ETS include the 27 that form the EU and Iceland, Liechtenstein, and Norway. The other 11 non-EU ETS countries are: Australia, Belarus, Canada, Japan, Kazakhstan, New Zealand, Russia, Switzerland, Turkey, Ukraine, and the United States of America. These 41 industralised countries were chosen since they have the highest emissions per capita and contribute most to climate change. The data from

UNFCCC are such that each country has data for the four sectors for 32 years. These emissions are measured in kilotons of carbon dioxide (kt of CO_2).

3.1.2. Emissions data by non-EU ETS sectors

The data on total greenhouse gas emissions in the 41 countries for the years 1990 to 2021 were collected from the European Union, Emissions Database for Global Atmospheric Research (EDGAR). The EDGAR database provides information on global past and present greenhouse gas emissions by country. This data was used to find the number of emissions for the non-EU ETS sectors. The number of emissions for the non-EU ETS sectors was derived by subtracting the cumulative sector-specific emissions collected by the UNFCCC from the total emissions collected by EDGAR. This data is such that each country has the number of emissions for the non-EU ETS sector for 32 years. These emissions are measured in kilotons of carbon dioxide (kt of CO_2). Given this, the treatment group consists of 150 country-sector combinations (30 countries subject to the EU ETS and 5 sectors) and the control group consists of 55 country-sector combinations (11 countries not subject to the EU ETS and 5 sectors). Thus, the treatment group includes 4,800 observations (150 country-sector combinations across 32 years) and the control group includes 1,760 observations (55 country-sector combinations across 32 years). Overall, the total number of observations in this analysis is 6,560.

3.1.3. Data for the control variables

In this analysis, five control variables are used: population, GDP, employment in the agricultural sector, employment in the industrial sector, and employment in the services sector. Data on these variables is collected from the World Bank Database. Population is measured as total population, GDP is measured in current US $, and employment in agriculture, industry, and services is measured as a percentage of total employment. In order to make the data on greenhouse gas emissions more comparable, country-sector emissions are derived in emissions per 1,000,000 inhabitants.

3.1.4. Descriptive Statistics of the data

Table 1: Descriptive statistics of country-sector emissions per 1,000,000 inhabitants (kt of CO_2)

	All emissions (1)	Treatment (2)	Control (3)	Difference (4)
Energy	8536.198	7654.853	10939.870	3285.015***
	[4438.030]	[3553.130]	[5581.578]	(318.836)
Industry	1088.899	1097.738	1064.793	-32.945***
	[798.008]	[894.099]	[439.985]	(37.184)
Agriculture	1386.892	1090.613	2194.926	1104.313***
	[1502.371]	[821.272]	[2385.947]	(129.904)
Waste	396.283	366.118	478.552	112.435***
	[221.175]	[176.491]	[297.204]	(16.834)
Non-EU ETS	1020.719	997.483	1084.090	86.607***
sectors	[1323.319]	[1383.521]	[1142.551]	(75.515)
Observations	6560	4800	1760	6560

Note: Table 1 provides information on the average emissions generated in each sector overall (presented in column (1)), for the treatment group (presented in column (2)), and control group (presented in column (3)). The treatment is all those countries subject to the EU ETS policy whereas the control is those that are not. Column (4) provides the differences between the average emissions of the two groups. Standard deviations are reported in square brackets and robust standard errors are presented in parentheses. The values are rounded to 3 d.p. *$p<0.10$, **$p<0.05$, ***$p<0.01$.

Table 1 reports the average overall country-sector emissions per 1,000,000 inhabitants, those of the treatment and control groups, and the difference between the two. Column (1) shows that the energy sector is the largest emission generating sector compared to all sectors included in this analysis. The overall differences in column (4) show that, apart from the industry sector, the control group generates more emissions per 1,000,000 inhabitants than the treatment group. Specifically, the table shows that the maximum difference between the two groups comes from the energy sector where on average, the countries not subject to the EU ETS policy generate 3,285.015 kt of CO_2 more than those subject to the EU ETS. The minimum difference arises from the non-EU ETS sectors wherein the control group generates 86.607 kt of CO_2 more than the treatment group. The only exception arises in the industry sector wherein the treatment group produces more emissions per 1,000,000 than the control group. Column (4) also confirms that these differences between the treatment and the control group are significant.

3.2. Methodology

In order to assess the effectiveness of the EU ETS, a difference-in-difference method will be applied. This method allows to estimate the effect of a specific policy intervention in a treatment group by comparing it to a control group (*Difference-in-Difference Estimation*, 2023). In this research, the number of emissions in each sector for the countries that implemented the EU ETS will be compared to the non-EU ETS sectors and countries. The treatment effect in this difference-in-difference approach is found through the average change between the treatment and control groups.

A vital assumption to ensure internal validity when implementing this method is the parallel trends assumption. This assumption requires that the relative outcome of the EU ETS countries and non-EU ETS countries in the treatment trend the same way as the relative outcome of the EU ETS countries and the non-EU ETS countries in the absence of treatment (Olden & Møen). To test the assumption, a statistical test and graphical inspection will be conducted. If the pre-intervention trends between the treatment and control group run parallel, this assumption will be satisfied. In case this assumption does not hold, the causal estimate will be biased (*Difference-in-Difference Estimation*, 2023).

Following Lechner (2010), the notation and identification strategy of the difference-in-difference method is derived. The equation that will be analysed is shown and explained below. The variable of interest is the triple interaction term denoted by β_7 which shows whether the country-sectors included in the EU ETS produce lower levels of emissions per 1,000,000 persons than the country-sectors not included in the EU ETS. Mathematically, the coefficient of the interaction between ETS countries, post-treatment, and the ETS sectors presents the treatment effect (here, the coefficient is β_7). This is because difference-in-difference assumes that the treatment effect is not constant over time but varies depending on when the policy (treatment) was implemented, inferring that the treatment effect can be larger or smaller in different time periods. Therefore, to capture this time-varying treatment effect, the difference-in-difference method uses the interaction which allows the treatment effect to vary over time and accounts for any differences in the trends between the treatment and control groups. Overall, the interaction effect enables the estimation of the treatment effect while controlling for any pre-existing differences between the treatment and control group.

$$Y_{its} = \alpha + \beta_1 ets_i + \beta_2 post\_treatment_t + \beta_3 sector_s + \beta_4 ets_i \times post\_treatment_t + \beta_5 ets_i \times sector_s + \beta_6 post\_treatment_t \times sector_s + \beta_7 ets_i \times post\_treatment_t \times sector_s + \beta_8 population_i + \beta_9 GDP_i + \beta_{10} employagri_i + \beta_{11} employind_i + \beta_{12} employserv_i + \gamma_{1i} + \gamma_{2t} + \gamma_{3s} + \varepsilon_{its} \quad (1)$$

Where:

i denotes each country, *t* denotes the pre- and post-intervention periods, and *s* refers to each sector.

Y_{its} is the number of emissions per 1,000,000 inhabitants in country *i* at point *t* for sector *s*.

ets_i is a binary variable where it equals 1 if the country is subject to the EU ETS and 0 otherwise.

$post\_treatment_t$ is a binary variable where it equals 1 if it is the post-intervention period and 0 if it is the pre-intervention period. The intervention periods are 2007, 2012, and 2020.

$sector_s$ is a binary variable where it equals 1 if the sector is included in the EU ETS and 0 otherwise.

$population_i$ denotes the population of each country. It is measured in total population.

GDP_i refers to the GDP of each country and is measured in current US $.

$Employagri_i$ denotes the employment in the agricultural sector for each country. It is measured as a percentage of total employment.

$Employind_i$ measures the employment in the industrial sector for each country. It is measured as a percentage of total employment.

$Employserv_i$ refers to the employment in the services sector for each country. It is measured as a percentage of total employment.

γ_{1i} are country fixed effects.

γ_{2t} are year fixed effects.

γ_{3s} are sector fixed effects.

ε_{its} is the error term.

Issues of endogeneity arise when the treatment variable is correlated with the error term, thus biasing the estimates of the treatment effect. When implementing a difference-in-difference regression, several sources of endogeneity can arise. One such issue is the selection bias. This occurs when assignment to treatment is not random, thereby leading to differences between the treatment and control groups pre-intervention. In this research, this is an important caveat since the treatment of being subject to the EU ETS policy is not random. It applies to all countries within the EU and does not include those outside of this economic union. Therefore, it can be concluded that the difference-in-difference regression suffers from selection bias. Another source of endogeneity are spillover effects wherein the treatment of being in the EU ETS can have spillover effects on the control group. This is an important issue to consider given the dire need for policies aimed at reducing climate change. If it seems that the EU ETS has been effective in reducing emissions, other countries may follow similar policies. If these spillover effects on the control group are correlated with the outcome variable, the number of emissions, it can lead to endogeneity and biasedness of the outcome. Thirdly, if there are time varying factors, like changes in economic conditions, that affect both the treatment assignment and outcome variable, it can bias the treatment effect. However, to reduce time-varying confounders, data on population, GDP, and employment in the different sectors is used to account for these.

4. Results

4.1. Parallel Trends Test

Before conducting the difference-in-difference approach and analysing the regression results, it is important to check for the parallel trends assumption.

Table 2: Parallel Trends test

	2007	2012	2020
Prob > F	0.811	0.716	0.324

Note: Table 2 presents the parallel trends test for the three intervention periods, 2007, 2012, and 2020. This test is based on the null hypothesis that the trends between the treatment and control groups are parallel. The sample includes 150 treated country-sector combinations and 55 control country-sector observations for 32 years (thus a total sample of 6,560). Values are rounded to 3 d.p. *p<0.10, **p<0.05, ***p<0.01.

Table 2 presents the results of a parallel trends test. The null hypothesis is that the trends between the treatment and control groups are parallel. Given that the p-values for all three intervention periods are insignificant at the 99%, 95%, and 90% significance levels, the test fails to reject the null hypothesis. This means that there is not enough evidence to reject the hypothesis that the trends between the treatment and control groups are parallel. While the insignificant values provide some support for the assumption, given the data and sample used in this research, this test does not provide any conclusive evidence that the parallel trends assumption holds. Alternatively, and for better inference of this assumption, a graphical representation is also provided.

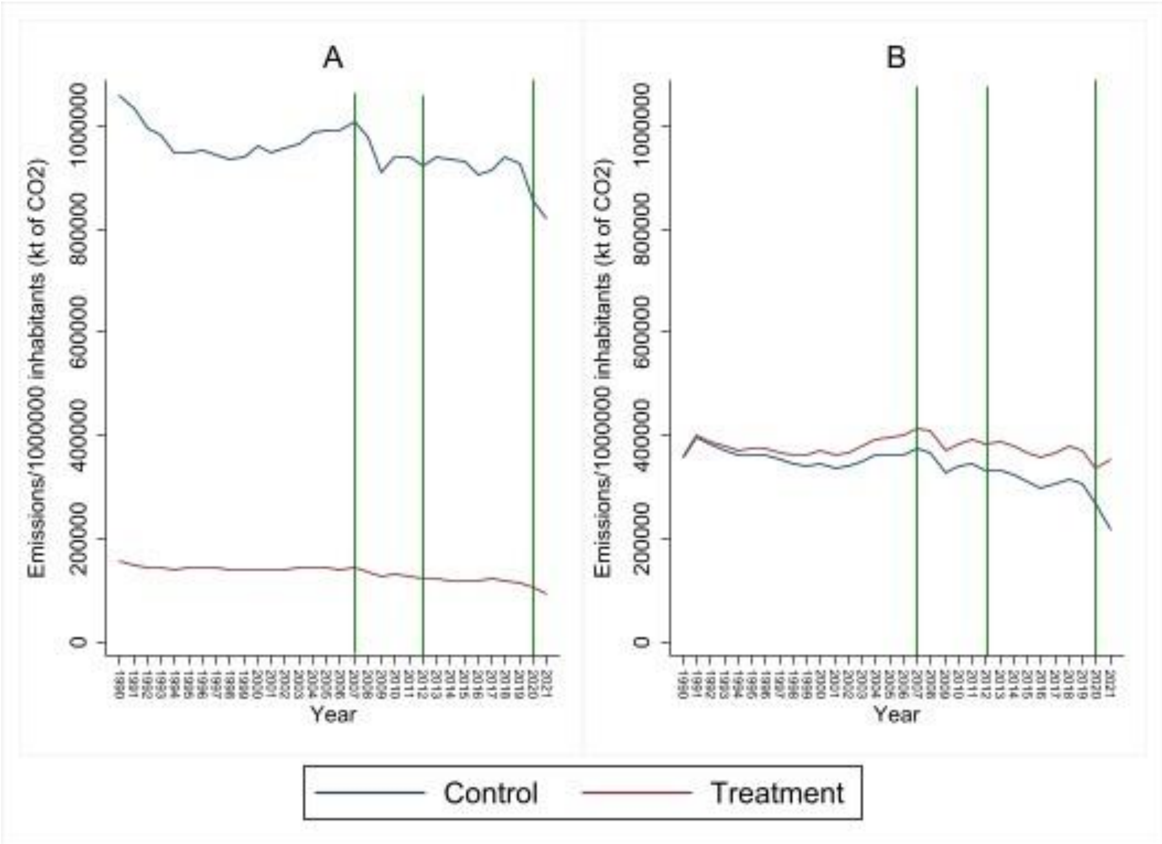

Figure 1: Graphical Analysis for Parallel Trends

Note: Figure 1 presents the observed means in Panel A and the parallel trends in Panel B for the control (non-EU ETS countries) and treatment (EU ETS countries). The x-axis presents the Year while the y-axis presents the emissions per 1,000,000 inhabitants in kt of CO_2. The green lines represent the division between the pre-intervention and post-intervention time periods in 2007, 2012, and 2020.

Figure 1 shows the graphical analysis for the parallel trends assumption. Panel A on the left shows the differences in observed means between the control and treatment group whereas panel B on the right shows the trends. The three green lines in each panel represent the last intervention period of the three stages of the EU ETS (2007, 2012, and 2020). Firstly, panel A shows that the control group has a notably larger average kiloton of carbon emissions compared to the treatment group, pre- and post-intervention. Specifically to post-intervention, it shows that on average, the treatment group has experienced stable reductions in their number of emissions through each intervention period. While the control group also sees a downward trend, it is not as stable as the treatment group. The control group also experiences larger fluctuations in emissions, as can be seen from the sudden decrease after 2007 and the sharp increase in 2008. Secondly, through visual inspection, it can be inferred that after the year 1993, the trends between the treatment and control seem to be parallel. This suggests that in the absence of treatment, the difference between the treatment and control groups is constant over time. Specific to this research, in the absence of the EU ETS policy, the difference between those country-sectors included in the EU ETS policy and those which are not included is constant over time. Since the graphical test suggests that the parallel trends assumption is met, and the statistical test could provide some support towards this assumption, causal inferences about the difference-in-difference results can be made. These results are discussed below.

4.2. Regression Results

As a means to finding the relationship between the number of emissions and the interaction of the treatment, intervention time period, and sector, and a way to test the hypothesis, a regression analysis with country, year, and sector fixed effects with country clustered standard errors is conducted. The results are provided in the table below.

Table 3: Regression results on country-sector emissions per 1,000,000 inhabitants

	Emissions per 1,000,000 inhabitants (1)
ets	
post_treatment2007	
post_treatment2012	
post_treatment2020	
ets_sector	
ets × post_treatment2007	43.556
	(125.249)
ets × post_treatment2012	-190.790
	(163.912)
ets × post_treatment2020	1.147
	(425.115)
ets × ets_sector	-1016.579*
	(519.565)
post_treatment × ets_sector2007	-256.131**
	(99.414)
post_treatment × ets_sector2012	-425.779***
	(128.016)
post_treatment × ets_sector2020	-929.575**
	(407.086)
ets × post_treatment × ets_sector2007	-98.332
	(139.471)
ets × post_treatment × ets_sector2012	89.621
	(146.072)
ets × post_treatment × ets_sector2020	121.428
	(429.413)
population	0.000
	(0.000)
gdp	-0.000*
	(0.000)
employmentagri	-33.791***
	(9.441)
employmentind	23.154**
	(11.070)
employmentserv	-1.902
	(4.780)
Constant	2925.108***
	(403.207)
Country fixed effects	Yes
Year fixed effects	Yes
Sector fixed effects	Yes
Observations	6560

Note: Table 3 presents the regression results on post-ETS emissions per 1,000,000 inhabitants in kt of CO_2 in 2007, 2012, and 2020. The variable of interest are ets × post_treatment × ets_sector2007, ets × post_treatment × ets_sector2012, and ets × post_treatment × ets_sector2020. Population, GDP, employment agriculture, employment industry, and employment services are used as control variables. Year, country, and sector fixed effects are used. Standard errors are clustered based on country and are reported in parentheses. Values rounded to 3 d.p. *p<0.10, **p<0.05, ***p<0.01.

Table 4: Regression results of the variables of interest

	Emissions per 1,000,000 inhabitants (1)
ets × post_treatment × ets_sector2007	-98.332 (139.471)
ets × post_treatment × ets_sector2012	89.621 (146.072)
ets × post_treatment × ets_sector2020	121.428 (429.413)
Country fixed effects	Yes
Year fixed effects	Yes
Sector fixed effects	Yes
Observations	6560

Note: Table 4 presents the regression results of the main variables of interest. This is done for better readability of the results. The emissions per 1,000,000 inhabitants are measured in kt of CO_2 and there are 6,560 total observations. Country, year, and sector fixed effects are included. Standard errors are clustered based on country and are provided in parentheses. Values rounded to 3 d.p. *p<0.10, **p<0.05, ***p<0.01.

Table 3 presents the regression results for Equation 1. It shows the effect of the EU ETS policy on the post-ETS country-sector emissions per 1,000,000 inhabitants in kt of CO_2. Country, year, and sector fixed effects are included. The triple interaction term between a country subject to the EU ETS, post intervention period, and EU ETS sectors depicts whether the EU ETS has been effective in reducing EU ETS country-sector emissions. Table 3 also reports five omitted variables due to multicollinearity. This can occur whenever one independent variable is correlated with another independent variable in the regression. In this analysis, since the triple interaction term is a product of a country being in the EU ETS policy (variable "ets"), the post-treatment time period after the first, second, and third stages of the policy (variable "post_treatment"), and the sectors included in the EU ETS (variable "ets_sector"), these three variables become correlated with the interaction, thus being omitted from the analysis. Table 4 depicts the coefficients of the variables of interest for easier readability and are the first set of results. As can be seen from Table 4, the interaction term produces a negative and insignificant result for the first post-intervention period in 2007 and an insignificant positive result for the second and third intervention periods in 2012 and 2020, respectively.

The null hypothesis states that there is no effect of the EU ETS on the number of emissions for the countries and sectors that are subject to this Policy in each of its stages. The statistically insignificant results suggest that there is not enough evidence to reject this null hypothesis. Since the p-value is greater than the significance level, the results generated here are not significantly different from zero, thus there is no strong evidence to support the presence of country-sector emissions reductions through the EU ETS. Any differences between the level of emissions of EU ETS specific country-sectors and non-EU ETS country-sectors are likely due to chance and random variability rather than a true relationship. Nonetheless, although the results found here are statistically insignificant, it may not necessarily imply that there is no effect at all. A small sample size, measurement error, or true but weak effects that this study was not sensitive enough to pick up could have led to null results.

Despite the statistically insignificant results, the magnitude of the effect in the three stages may still be of practical relevance. The decrease in the first stage could be a result of a new policy where firms in the countries and sectors within the EU ETS adjust to the new regulations. The increase in emissions per 1,000,000 inhabitants in the second stage in 2012 may perhaps be attributed to decrease in GDP growth. During this time, GDP growth in the countries subject to the EU ETS was decreasing (World Bank). As a result of this economic downturn, it is possible that firms search for cheaper alternatives to continue producing at elevated levels without increasing their costs. Similarly, in the third stage in 2020, there was a dramatic increase in GDP growth. World Bank data shows that the combined GDP growth in the countries subject to the EU ETS was –5.67% in 2020 which significantly increased to 5.47 in 2021. This substantial increase in GDP growth could result in the increase in emissions per 1,000,000 persons for this stage.

These results in Table 4 can still be relevant for policy-makers. Based on these results, the EU ETS policy could require considerable amendments to be effective in reducing emissions in countries and sectors subject to the policy. To do so, several studies cite the need for a decrease in the cap on the number of emissions that a firm is allowed to emit or the increase in price of the allowances to discourage purchasing more allowances to increase their emissions (Abrell et al (2021), Heiaas (2021), Laing et al (2013)). Compared to the related literature on similar topics, the number of EU ETS country-sector emissions per 1,000,000 inhabitants found here are relatively small. For example, the results from the study conducted by Laing et al (2013), who focus on the carbon emission reductions in the first two phases of the policy, concluded that between 2005 and 2007, the reductions were as large as 200 million tons (200,000 kt). This is contradictory to the results generated here as they suggest that although there is a reduction, it is quite minimal. Nonetheless, the results are consistent with those found by Heiaas (2021) who conducted research on the effectiveness of the EU ETS in reducing aviation-based emissions, where it is found that the policy had a limited impact.

Table 5: Effect of each sector on emissions per 1,000,000 inhabitants in kt of CO_2

	Emissions per 1,000,000 inhabitants
	(1)
Agriculture × ets × post_treatment2020	7.129
	(108.786)
Energy × ets × post_treatment2020	-620.782***
	(125.910)
Industry × ets × post_treatment2020	-27.401
	(37.729)
Waste × ets × post_treatment2020	-0.917
	(21.700)
Country fixed effects	Yes
Year fixed effects	Yes
Sector fixed effects	Yes
Observations	6560

Note: Table 5 provides the regression results for the variables of interest of each sector on emissions per 1,000,000 inhabitants in kt of CO_2. Column (1) presents the results on emissions in the third stage of the policy in 2020. Thus, the variables of interest are Agriculture × ets × post_treatment2020, Energy × ets × post_treatment2020, Industry × ets × post_treatment2020, and Waste × ets × post_treatment2020. The first and second stages are used as control variables in addition to population, GDP, employment in the agriculture, industrial, and service sectors. Country, year, and sector fixed effects are included. Standard errors are clustered based on country and are reported in parentheses. Values are rounded to 3 d.p. *** p<0.01, ** p<0.05, * p<0.1.

Table 5 shows how each sector within the EU ETS policy affects the number of emissions per 1,000,000 inhabitants in the third stage, thereby making it possible to analyse a specific sector and their impact on country-sector emissions. These are the second set of results. The complete regression table can be found in Appendix I, Table A1 where the first two stages of the EU ETS, country, and sector demographics (population, GDP, employment in the agriculture, industry, and service sectors) are controlled for, and country, year and sector fixed effects are applied. The results infer that in the third stage of the Policy, for those countries and sectors that are subject to the EU ETS, the energy sector had the largest impact on emission reductions, followed by the industrial sector, then the agriculture sector, and finally, the waste sector. This may suggest that the effect of the EU ETS is strongest in the energy sector, that is, the EU ETS policy contributes towards emissions reductions largely due to emission reductions in the energy sector. Given that this result is also significant, there is enough evidence to support the idea that the energy sector is the largest contributor to emission reductions for those countries subject to the EU ETS.

5. Robustness

Robustness checks can be undertaken to test the validity and reliability of the estimated treatment effects. In this research, the time period will be altered such that the first stage ends in 2005, the second stage in 2010 and the third stage in 2018. If the interaction terms from this regression are also found to be insignificant, it may strengthen the argument that there actually exists no relationship between the EU ETS and country-sector emissions reductions, as found in Section 4. This consistency across the different time periods could indicate that the results are unlikely to be influenced by extreme, short-term events.

Table 6: regression estimates of the variables of interest for the altered post-intervention periods.

	Emissions per 1,000,000 inhabitants (1)
ets × post_treatment × ets_sector2005	-228.308
	(188.413)
ets × post_treatment × ets_sector2010	238.9
	(200.9)
ets × post_treatment × ets_sector2018	258.067
	(176.891)
Country fixed effects	Yes
Year fixed effects	Yes
Sector fixed effects	Yes
Observations	6560

Note: Table 6 presents the regression results for the variables of interest for the altered intervention periods of 2005, 2010, and 2018. Population, GDP, employment in agriculture, industry, and service sectors are used as control variables. Country, year, and sector fixed effects are included. Standard errors are clustered based on country. Values are rounded to 3 d.p. *p<0.10, **p<0.05, ***p<0.01

Table 6 presents the regression estimates of an altered time period where the intervention years are now 2005, 2010, and 2018 for the variables of interest. The complete regression results can be found in Appendix II, Table A2. As can be seen from Table 6, the estimates for all three periods are insignificant. Given that both the main results and the robustness results are insignificant, it suggests consistency in the evidence within this paper. This may indicate that, using the data collected for this research, the effect of the EU ETS in country-sector emissions reductions may be non-existent. The lack of statistical significance in results of Table 4 and Table 6 indicate that there is insufficient evidence to support the effect of the EU ETS. Therefore, this robustness check reaffirms that the first set of results does not find sufficient data to reject the null hypothesis, and the effectiveness of the EU ETS was not detectable with the data used in this research.

6. Conclusion and Discussion

This paper explores the effectiveness of the EU ETS policy in reducing country-sector emissions per 1,000,000 inhabitants. It aims to answer the question to what extent was the European Union Emissions Trading System effective in reducing country-sector greenhouse gas emissions in its first three stages?

By applying a difference-in-difference approach, a regression analysis is conducted to measure the effectiveness of the Policy. Given insignificant results, there was not enough evidence to reject the null hypothesis that the there is no effect of the EU ETS on the country-sector emissions per 1,000,000 inhabitants. The results also infer that the energy sector is the largest contributor to the reduction in emissions per 1,000,000 persons and the agriculture sector is the least. The results generated in this research are quite different from the results found in other studies. The main difference lies in the statistically significant results found by other researchers, but also in magnitudes wherein the influence of the EU ETS is significantly large compared to this analysis. This can be attributed to a more refined dataset or estimation procedure than the one conducted in this research.

This research does not come without its limitations. Firstly, national environmental policies that are implemented in the countries in the control group were not accounted for. Although country, year, and sector fixed effects were included in the regression, these only control for the variation between the countries at each year in each sector. However, the effects of the environmental policy could have led to certain changes within the control group that could have affected the results. Moreover, since the coefficient of a triple interaction term is the variable of interest, it is not clear to what extent do each of the three variables contribute to the emissions reductions. Although an overall effect is observed, there is ambiguity in which variable provides the largest effect and which the smallest. With regard to the dataset, findings could be more accurate if the number of non-sectors and sectors was identical since it provides a more equal comparison and estimation between the treatment and control groups.

Further research needs to be conducted on the drivers of the findings from this research. Currently, the results imply that the EU ETS was able to have a limited effect on the number of emissions for those countries subject to the Policy. However, it is unclear what exactly is leading to the reduced emissions. Moreover, further research can be conducted on the area of finding the effect of each of the variables in the triple interaction and how those contribute towards the goals of the EU ETS. Another area of further research could include conducting sectoral-specific analyses to provide insights into the impact of the EU ETS across various industries. This can assess how different sectors would respond to the EU ETS and evaluate the effectiveness of the system in driving emission reductions within each sector. This can provide sector-specific policy recommendations and identify sectors that may require additional support to achieve reduction targets.

As multiple researchers have highlighted, an important policy implication is that the EU ETS policy needs to be implemented alongside other complementary policies in order to reach the desired reductions in emissions. An example of a complementary policy is to increase public investment in research, development, and innovation in low-carbon technologies to support the transition to a sustainable economy. Additionally, policymakers can focus on EU ETS sectors that produce the largest amounts of emissions and implement policies for these specific areas of the economy. For example, performance standards, emission limits, or technology requirements can help accelerate emissions reductions. Overall, a well-designed mix of policies that considers more than just the EU ETS can create a more robust and comprehensive framework to address climate change and achieve the desired targets.

Appendix

I. Table A1: Effect of each sector on emissions per 1,000,000 persons in kt of CO_2

	Emissions per 1,000,000 inhabitants (1)
Agriculture × ets × post_treatment2020	7.129
	(108.786)
Agriculture × ets × post_treatment2007	-348.064
	(252.338)
Agriculture × ets × post_treatment2012	71.490
	(53.629)
Energy × ets × post_treatment2020	-620.782***
	(125.910)
Energy × ets × post_treatment2007	-784.535**
	(302.664)
Energy × ets × post_treatment2012	-574.311***
	(93.187)
Industry × ets × post_treatment2020	-27.401
	(37.729)
Industry × ets × post_treatment2007	64.053
	(68.346)
Industry × ets × post_treatment2012	12.935
	(19.244)
Waste × ets × post_treatment2020	-0.917
	(21.700)
Waste × ets × post_treatment2007	24.216
	(30.758)
Waste × ets × post_treatment2012	4.273
	(11.201)
population	0.000
	(0.000)
gdp	-0.000**
	(0.000)
employmentagri	-30.962***
	(8.890)
employmentind	15.001
	(10.903)
employmentserv	0.568
	(4.795)
Constant	2359.300***
	(251.087)
Country fixed effects	Yes
Year fixed effects	Yes
Sector fixed effects	Yes
Observations	6560

Note: Table 5 provides the regression results of each sector on emissions per 1,000,000 inhabitants in kt of CO_2 in 2020. Thus, the variables of interest are Agriculture × ets × post_treatment2020, Energy × ets × post_treatment2020, Industry × ets × post_treatment2020, and Waste × ets × post_treatment2020. The first and second stages are used as control variables in addition to population, GDP, employment in the agriculture, industrial, and service sectors. Country, year, and sector fixed effects are included. Standard errors are clustered based on country and are reported in parentheses. Values are rounded to 3 d.p. *** p<0.01, ** p<0.05, * p<0.1.

II. Table A2: regression estimates with altered post-intervention times.

	Emissions per 1,000,000 inhabitants (1)
ets	
post_treat2005	
post_treat2010	
post_treat2018	
ets_sector	
ets × post_treatment2005	190.924
	(164.905)
ets × post_treatment2010	-364.216**
	(162.591)
ets × post_treatment2018	11.886
	(270.389)
ets × ets_sector	-1004.070*
	(523.417)
post_treatment × ets_sector2005	17.322
	(161.136)
post_treatment × ets_sector2010	-647.859***
	(159.047)
post_treatment × ets_sector2018	-445.476*
	(249.653)
ets × post_treatment × ets_sector2005	-228.308
	(188.413)
ets × post_treatment × ets_sector2010	258.067
	(176.891)
ets × post_treatment × ets_sector2018	-11.577
	(268.143)
Population	0.000
	(0.000)
gdp	-0.000**
	(0.000)
employmentagri	-33.617***
	(9.394)
employmentind	22.739**
	(11.116)
employmentserv	-1.763
	(4.807)
Constant	2911.972***
	(408.820)
Country fixed effects	Yes
Year fixed effects	Yes
Sector fixed effects	Yes
Observations	6560

Note: Table 5 presents the regression results on post-ETS emissions per 1,000,000 inhabitants in kt of CO_2. The variable of interest are the 13th, 14th, and 15th rows with variables ets × post_treatment × ets_sector2005, ets × post_treatment × ets_sector2010, and ets × post_treatment × ets_sector2018. Population, GDP, employment agriculture, employment industry, and employment services are used as control variables. Year, country, and sector fixed effects are also included. Standard errors are clustered based on country and are reported in parentheses. Values rounded to 3 d.p. *p<0.10, **p<0.05, ***p<0.01.

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