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Do Emissions Trading Systems (ETS) help the reduction of GHG emissions? An Investigation in the European context.

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Introduction

Looking at the top ten warmest years on record, we can observe that all have occurred since 2010. Among them, 2022 is the sixth on the list; +0.86°C above the pre-industrial average. The effects of this increase are more visible than ever. During that summer, Europe and North America were hit by extreme heat waves and drought. At the same time, more than 30 million people in China and Pakistan were affected by severe floods.[1] This year's condition is not significantly different from the previous one; new temperature records were established and extreme weather events are occurring with increasing frequency and intensity in several regions of the world. [2] At this pace, in less than 30 years the temperature increase will be around 2.5°C (IMF, 2020). The losses in terms of biodiversity and economic growth will be uncountable. In response to this challenge, economists and policymakers are actively exploring strategies to counteract this trend in a sustainable and impactful way. Among these strategies, carbon pricing is the one that is getting more attention, but from a wide range of economic viewpoints. Due to the relatively short history of such policies and the limited amount of data, some economists initially questioned the effectiveness of carbon pricing. This scepticism generated debate and disagreement within the field. However, as more data has been accessible and carbon pricing schemes have been implemented by an increasing number of countries, the consensus has evolved. The emerging consensus recognises that carbon prices can generate significant reductions in carbon emissions. While debates regarding its precise effectiveness remain, the prevailing view now centres more on the degree of its impact rather than its fundamental efficacy. This shift in the literature emphasises the evolution of our knowledge about carbon pricing and its growing role in tackling climate change.

In this study, I investigate the effectiveness of the main carbon pricing policy adopted in Europe, the European Union Emissions Trading System (EU-ETS), in lowering emissions using two approaches. First, I investigated the impact of the EU-ETS on carbon dioxide (CO2)

[1]Retrived [July, 2023], from: www.ncei.noaa.gov/news/global-climate-202212

[2]Retrived [August, 2023], from:www.cnn.com/2023/07/05/world/hottest-day-world-climate-el-nino-intl/index.html

and nitrous oxide (N2O) emissions across the European continent. Second, I investigated the link between environmental policy and company performance, focusing on European firms' Environmental, Social, and Governance (ESG) scores. This dual-method approach fulfils two important functions. It addresses a critical policy question by examining the alignment of regulatory frameworks and business sustainability activities, shedding light on the relationship between them. Second, it would provide insights on how market-driven incentives, such as the EU-ETS, influence business behaviour and environmental effects.

I found out that the EU-ETS has shown notable effectiveness in decreasing CO2 emissions from 2013 to 2021, reaching a significant decrease of around 13%. However, its influence on N2O emissions over the same time period was minimal, with a reduction of less than 1.3%. Furthermore, no substantial relationship has been found between the EU-ETS and the business performance of European corporations. Despite the observed drop in emissions, the median E score for European corporations has fallen during the analysed time period, raising concerns about the alignment of environmental legislation and corporate sustainability measures. These findings shed light on the complex dynamics of carbon pricing legislation and its interactions with business behaviour and environmental impacts. Moreover, the analysis proposed in this thesis should be viewed as a tool for policymakers to understand the effectiveness of carbon pricing and ETS schemes in relation to GHG emissions.

The thesis is organised as follows: Chapter 1 provides background information to understand the path that led to carbon pricing policies. Chapter 2 is the literature review. Chapter 3 contains data, identification strategy and results. The last chapter concludes.

1. The path toward carbon pricing

This chapter gives the background for understanding carbon pricing. I highlight the reason for and relevance of implementing carbon pricing systems by tracing the historical growth of climate change concerns from their genesis to current policy developments. In addition, the chapter dives into the current landscape of Emission Trading Systems (ETS) in major economies.

1.1 Preamble

In this section, I discuss environmental policies that are important to understand the theoretical and practical background that led to the adoption of carbon pricing schemes. The figure on the right of 1.1 gives us a vivid view that during the last 30 years, with the contribution of the Montreal Protocol, the consumption of ozone-depleting substances has decreased by more than 90%. As the World Meteorological Organisation (WMO) reports, by 2045 the ozone layer above the Arctic will be fully healed, returning to pre-1980 levels.[1] The second graph on the 1.1 shows the effect of the Acid Rain Program (ARP) promoted by the United States Environmental Protection Agency (EPA) during the 1990's. The ARP was created to reduce the amount of Sulphur Dioxide (SO2) and Nitrogen Oxide (NOX) emitted by power plants in the United States in order to lower the risk of acid rain. For the first time, a cap-and-trade system was implemented and in 20 years the amount of SO2 and NOX emissions has decreased by more than 70%.

[1] Source: ozone.unep.org/system/files/documents/Scientific-Assessment-of-Ozone-Depletion-2022-Executive-Summary.pdf

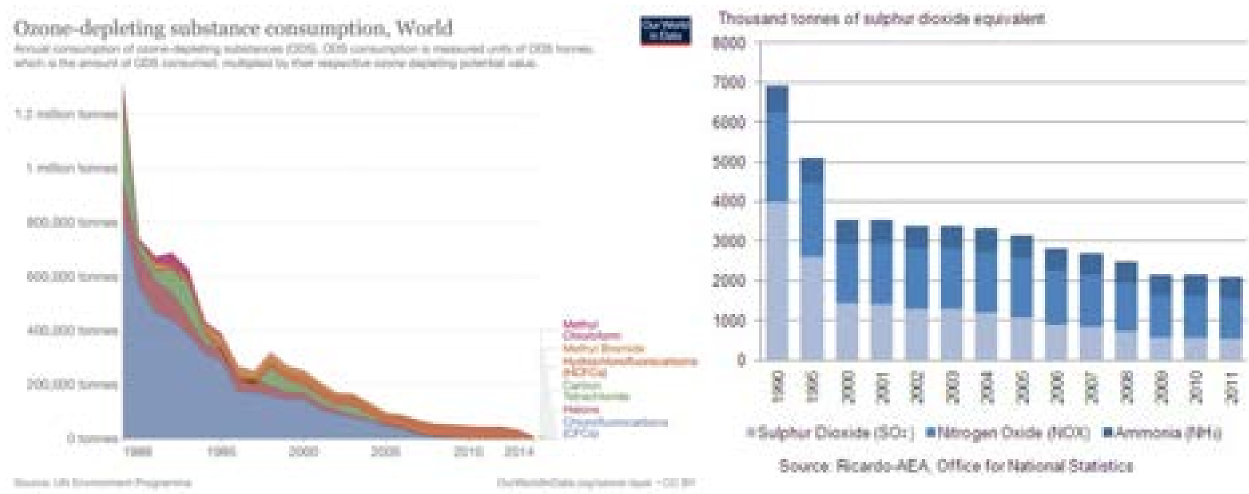

Figure 1.1: The effects of the Montreal Protocol and the Acid Rain Program. (Retrived [July,2023], from: ourworldindata.org/ozone-layer and baileymattas.weebly.com/statistics.html)

These past experiments demonstrate that once a reduction goal is established and the rules are set, economies can achieve their aims in a relatively short amount of time and possibly without relevant economic loss.[2] To complete our background, we should mention the United Nations Framework Convention on Climate Change (UNFCCC). Signed by 154 nations on June 12, 1992, they committed to stabilizing greenhouse gas (GHG) concentrations in the atmosphere "at a level that would prevent dangerous anthropogenic interference with the climate system" (Art. 2, UNFCCC). The parties of the Convention started to meet annually in 1995 and since, in the so-called "Conference of Parties" (COP), to assess their progress in tackling climate change. The two most important COPs are COP3, where the Kyoto Protocol was signed and COP21, which resulted in the Paris Agreement. Entered into force in 2005, the Kyoto Protocol is the first international agreement that operationalizes the UNFCCC, committing developed countries to limit and reduce GHG emissions and establishing mechanisms for international cooperation and market-based mechanisms to help achieve these targets.[3] The two mechanisms are the Emissions Trading and the Clean Development Mechanism. The emissions trading mechanism allowed countries to buy and sell emissions

[2]As declared by the EPA here: https://www.epa.gov/acidrain/acid-rain-program-results

[3]Under the Kyoto Protocol, developed nations agreed to cut GHG emissions by an average of 5.2% below 1990 levels between 2008 and 2012.

credits, while the Clean Development Mechanism allowed developed countries to invest in emissions reduction projects in developing countries. However, the Kyoto Protocol has been criticised for its limited coverage of emissions and for the fact that some of the world's largest emitters, including the United States and China, did not participate.[4] Nonetheless, the Protocol can be considered a milestone, having raised awareness about the urgent need to address climate change at a global level. The Paris Agreement was adopted in 2015 and came into effect in 2016. The goal of the Paris Agreement is to limit global warming "well below 2°C" above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C. The agreement includes commitments from all countries, both developed and developing, to reduce their greenhouse gas emissions and to submit nationally determined contributions (NDCs) outlining their targets and strategies. Unlike the Kyoto Protocol, the Paris Agreement does not set specific targets for emissions reductions but instead relies on countries to set their own targets and to regularly report on their progress. The agreement also includes a transparency framework that requires countries to report on their emissions and to regularly update their NDCs.[5] The Paris Agreement builds on the foundation laid by the Kyoto Protocol by expanding the scope of emissions reductions to include all countries and by including mechanisms for transparency and accountability. However, the Paris Agreement does not replace the Kyoto Protocol, and some countries, including Japan and Russia, continue to participate in the Kyoto Protocol while also being parties to the Paris Agreement. Both agreements have contributed to the development of emissions reduction policies and technologies, and they constitute the basis on which Carbon pricing practices are built.

1.2 What is Carbon Pricing

According to the World Bank (2023) *"Carbon pricing is an instrument that captures the external costs of greenhouse gas (GHG) emissions and ties them to their sources through a price, usually in the form of a price on the carbon dioxide (CO2) emitted"*. The external costs mentioned are the ones that society as a whole bears. Damage to crops due to heat waves and droughts,

[4]The US never ratified the Protocol. China, as well as India, never had a binding target

[5]Source: unfccc.int/process-and-meetings/the-paris-agreement

health care costs, property loss due to flooding, and sea level rise are examples provided. Putting a price on GHG emissions provides an economic signal to the emitters and represents an incentive to reduce emissions. As a result, the overall environmental objective is met in the "most flexible and least-cost way to society" (ibid.). The two main ways that countries are adopting to implement carbon pricing are Carbon Tax and Emission Trading Schemes (ETS). Carbon Tax is a pigouvian tax, which is a tax on a market transaction that creates a negative externality (in our case, CO_2), borne by individuals not directly involved in the transaction. It should be equal to the cost of the negative externality. It raises the cost of emission-intensive goods and services while decreasing the cost of non-intensive ones. This reduces the incentive to emit GHGs, thereby minimising the consequences of climate change. Because of its broad tax base, the revenue must be used in a variety of ways, including incentivizing the development of new green technology and lowering taxes for the most vulnerable segments of the population (Parry, 2021). The main positive aspect of a carbon tax is that governments can implement it in a fast and effective way, like any other tax. The most valuable example of the implementation of a carbon tax can be found in Sweden. It was introduced in 1991, and in 2022, it was 118€/tCO2. In thirty years, their GHG emissions have decreased by 35% and the GDP increased by 83% compared to 1990. [6] ETSs (also known as cap-and-trade systems) are more complex to implement than taxes, but they provide incentives to companies due to their way of working. Under an ETS, the government limits the amount of CO_2 that an industry may release. It divides the cap into permits, which it either distributes or sells to businesses. These permits can be transferred between companies in a certain market. Every year, the cap is reduced, and the permit pool becomes more expensive. As shown in figure 1.2, 73 carbon pricing initiatives are actually in force. They cover 11.66 GtCO2, which represents 23% of global GHG emissions. ETSs cover 17.64% of them. [7]

[6] Source: www.government.se/government-policy/swedens-carbon-tax/swedens-carbon-tax/

[7] https://carbonpricingdashboard.worldbank.org/

Figure 1.2: Summary map of regional, national and subnational ETS initiatives. (Retrived [July,2023], from: icapcarbonaction.com/en/ets)

1.2.1 ETSs in the major economies

Here I describe the actual situation in the six regions mentioned by Parry *et al.* (2021). [8] In 2030, these countries will account for more than 60% of global GHG emissions. The purpose of this examination is to comprehend the efforts made by these nations to tackle climate change and to highlight the disparities between their actions. The sources for these descriptions are the official government website of the mentioned countries/project. [9]

[8] Canada, China, European Union, India, United Kingdom and United States

[9] The only exception is China. All the information about its ETS is from: icapcarbonaction.com/en/ets/china-national-ets

Canada

Canada implemented a federal carbon pricing scheme in 2019, known as the Greenhouse Gas Pollution Pricing Act (GGPPA). The GGPPA sets a minimum price of CAD$65 per tonne of carbon dioxide equivalent (CO2e) in 2023, which will increase by CAD$15 per year until it reaches CAD$170 per tonne in 2030. Canadian jurisdictions have the freedom to create and implement their own pricing systems, customised to local requirements, as long as they fulfill minimal national stringency criteria (known as the federal benchmark). According to the existing benchmark, carbon pricing should apply to the same sources as British Columbia's carbon tax (fuels used for electricity, heating, transportation and industry). British Columbia's carbon tax was CAD $50 per tonne of CO2e in 2022. Québec has a cap-and-trade system that sets a cap on emissions, which decreases over time. Ontario aligned its previous cap-and-trade system in 2018 with the one in Québec. The federal and provincial carbon pricing mechanisms are intended to provide a price signal to reduce GHG emissions and encourage investments in low-carbon technologies. The revenue generated from the federal carbon pricing scheme is returned to Canadians through various measures, such as rebates, to help offset the impact on households and businesses.

China

China's carbon pricing mechanisms consist of two main elements: a pilot emissions trading scheme and a national carbon market. The pilot emissions trading scheme was implemented in eight regions and cities (Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong, Fujian and Shenzhen) in 2011. The allowances were mostly freely allocated in these pilot schemes and then traded in regional secondary markets. Started in 2021, the national carbon market mainly covers the power sector, a total of 2,162 companies, and 400 million metric tonnes of CO2 per year, accounting for 40% of national emissions. The carbon allowances are freely allocated based on a company's historical emissions and production levels. However, the allocation mechanism will shift to a benchmark-based approach in the future. The price of allowances is determined by market supply and demand in the secondary market, with a government-set price ceiling and floor. The regional ETS will be gradually included in the national one.

European Union

The European Union Emission Trading System (EU-ETS) is the oldest and largest carbon market in the world. The evolution of the EU ETS has been divided into stages. The first phase lasted three years, from 2005 to 2007. This was a trial period to prepare for phase two, in which the system had to be efficient in order to help the EU fulfil its Kyoto targets. Almost all allocations were freely provided at the national level during this early period. In the absence of reliable emissions data, guesses were used to determine phase one limitations. The carbon price declined sharply in 2007 when it became clear that the entire number of allowances granted surpassed overall emissions, finally settling at 0€ since phase one allowances could not be transferred to phase two. The second phase lasted from 2008 to 2012, corresponding with the first commitment period of the Kyoto Protocol, during which the EU ETS members had to reach concrete emission goals. Because confirmed yearly emissions statistics from the pilot phase were now available, the permit ceiling was decreased in phase two based on actual emissions. The fraction of free allocation decreased significantly; numerous nations began to arrange auctions, and corporations were permitted to purchase a limited number of foreign credits. The commission also began to expand the system to include new gases and industries; in 2012, the aviation industry was included, but this only applied to flights inside the European Economic Area. Notwithstanding these adjustments, EU carbon pricing remained stable. This was mostly due to the 2008 economic crisis, which resulted in greater-than-expected emissions reductions, resulting in a substantial surplus of permits and credits pulling down prices. The third phase began in 2013 and went through the end of 2020. Learning from the previous stages' lessons, the system was significantly altered in a number of crucial areas. The new system, in particular, relies on a single, EU-wide cap on emissions instead of the previous national caps; auctioning became the default method for allocating allowances instead of the previous free allocation, and harmonised allocation rules apply to the allowances that are still allotted for free, and the system covers more sectors and gases, including nitrous oxide (N2O) and per-fluorocarbons (PFC) in addition to CO2. The Commission postponed the auction of 900 million permits in 2014 to resolve the surplus of emission allowances that had accumulated during the Great Recession ('back-loading'). Eventually, the Commission established a market stability reserve (MSR), which went into effect in January 2019. By altering the supply of allowances to be auctioned, this reserve aims to minimise the existing surplus of allowances and strengthen the system's resilience to significant shocks. For that purpose, in the latter years of phase three, back-loaded allowances were moved to the reserve rather than auctioned, and unallocated allowances were also transferred to the reserve. The current fourth phase lasts from 2021 until 2030. In early 2018, the statutory basis for this trading time was updated. To meet the EU's 2030 emission reduction objectives, the yearly reduction rate in total permits increased from 1.74% to 2.2%, and the market stability reserve was strengthened to boost the EU ETS's resilience to future shocks. The EU-ETS covers around 40% of the total emissions; the sectors are: power, industry and domestic aviation. The actual members of the EU-ETS are the 27 states of the European Union plus Norway, Liechtenstein and Iceland. 1.3 presents a comprehensive review of the EU-ETS history.

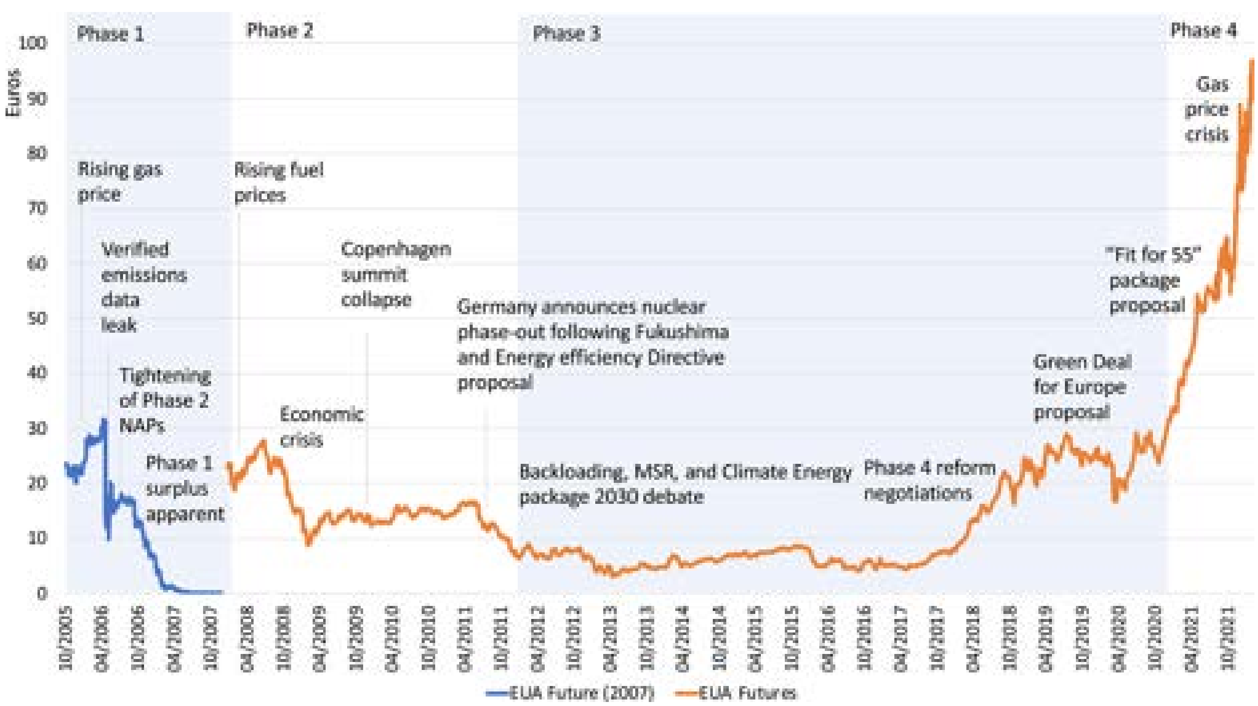

Figure 1.3: History of EU-ETS prices. (Retrived [July,2023], from: doi.org/10.1002/wcc.796)

India

India actually does not have any kind of carbon tax or ETS but in 2021, the Bureau of Energy Efficiency (BEE) of India proposed a phased national carbon market plan, proposing a voluntary market with a domestic offset mechanism and a future required compliance market. An amendment proposal to the 2001 ”Energy Conservation Act” was enacted in July 2022, creating a legal foundation for the domestic carbon market and enabling carbon credit issuing. In October 2022, BEE suggested transforming the ”Perform, Achieve, and Trade” (PAT) program into a compliant carbon market. The voluntary market is scheduled to start in July 2023, with the compliance market following in 2024. In May 2022, Gujarat's government declared its willingness to implement a state-level cap-and-trade system covering emissions from big industrial and electricity sources.

United Kingdom (UK)

The UK has implemented a carbon pricing mechanism known as the Carbon Price Support (CPS), which was introduced in 2013 to provide a price signal to reduce GHG emissions from power generation. The CPS applies to the UK's electricity and industrial sectors and sets a minimum price for carbon dioxide emissions from fossil fuels. The CPS has been effective in reducing the UK's greenhouse gas emissions, and the UK government has committed to continuing the scheme until at least 2027. After Brexit, the country has implemented its own emissions trading scheme, the UK Emissions Trading Scheme (UK ETS). It replaced the UK's participation in the EU ETS. The UK ETS has similar objectives to the EU ETS, including reducing greenhouse gas emissions and providing a price signal for low-carbon investment. The UK government has set an initial cap on emissions for the UK ETS, and the scheme is expected to evolve over time to align with the UK's climate targets.

United States (US)

As we can see in figure 1.2, the US does not have a federal carbon pricing policy in place, but some states have implemented their own policies. The lack of a national carbon pricing policy is a significant gap in the US approach to mitigating greenhouse gas emissions. California operates a cap-and-trade program that sets a limit on greenhouse gas emissions and allows for the trading of emissions credits. It is made to help the state to achieve the 2030 GHG reduction target of at least 40% below 1990 levels, and it covers about 85% of the state's emissions. It is also bilaterally linked with the ETS in Québec. In addition to this, twelve states in the Northeast operate the Regional Greenhouse Gas Initiative (RGGI) (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia), which is a cap-and-trade program that sets a cap on emissions from power plants. The RGGI has helped reduce emissions from the power sector in the region by 50% since 2005, and it covers about 20% of US power sector emissions. Despite the presence of these state-level carbon pricing policies, they cover only a small percentage of the US population and do not provide the comprehensive price signal needed to encourage emissions reductions across the economy. A national carbon pricing policy could provide the needed price signal to accelerate the transition to a low-carbon economy in the US. New ETS are under consideration in North Carolina, Pennsylvania and the state of New York.

On figure 1.4 we have a quite comprehensive view of the allowances' prices for the analysed ETSs. As displayed, the EU-ETS has the higher price for the allowances, around 90€/tCO2, followed by the ones of the UK-ETS. This can be explained by the fact that the latter is based on the former, and the UK government wanted to use the same mechanisms and rules already implemented when it was part of Europe. The second-oldest ETS implemented is the RGGI, but, despite its long history, the prices remained stable under 20€/ton CO2. We can also see the links created between the ETSs of California, Québec and Ontario and how the prices have increased over the last few years. China, on the other side, is the newest ETS, with an average price of 7€/ton CO2.

Overall, an increasing number of governments are instituting carbon pricing regimes in order to better comply with the Paris Agreement. Japan, after the results achieved by the Tokyo cap-and-trade program, is planning to start its national ETS in 2026. New Zealand launched its ETS in 2008, including a variety of sectors that have never been regulated in other ETS. [10]

[10] Which are: forestry, energy, industry, fossil fuels, waste, and synthetic GHGs.

Figure 1.4: Prices for one ton of CO_2 in the mentioned ETSs.(Retrived [July,2023], from: icapcarbonaction.com/en/ets-prices)

Devoloping countries have also started their ETS in recent years. The most valuable examples are in Mexico and Indonesia, where ETSs began to operate this year with their pilot phase. Still, it is undeniable that there are significant disparities across nations in terms of permitted pricing and commitment to meet their 2030 target. Another key point to emphasise is that, despite the adoption of various schemes in both developed and developing countries, only a few of them have an annual decreasing cap on total emissions already, and more efforts are needed to decarbonise the economy.

To sum up, this chapter provides an overview of the current situation of carbon pricing around the world. Despite the absence of the United States as a whole, it is obvious that developed economies are making greater efforts to tackle climate change. Europe is leading the way with its ETS to better understand how to implement this system. Greater economic cooperation is required to reach net zero emissions by 2050, and policymakers must collaborate and exchange knowledge on how to effectively implement carbon pricing regulations.

2. Assessing the effectiveness of carbon pricing: a literature review

This chapter contains the literature review about carbon pricing measures and ETS. I first explain the methodology used to review the literature and briefly describe my sample of papers. Then, in the second section, I present the review, with a table that summarises the main elements of each paper and a discussion of the ones that are closely related to my empirical analysis.

2.1 Methodology

To find the right literature to understand the topic, I used Google Scholar and EconPapers and searched for the following terms:

- Carbon pricing
- Carbon tax
- Emission trading scheme
- Carbon pricing effects
- Carbon pricing efficacy
- Carbon Pricing and ESG

I have read the abstracts of all the articles in the first 5 pages returned in each keyword search. Due to the number of studies and the short history of carbon pricing practices, I selected only articles published after 2018. The reasons behind this decision are related to the short history of carbon pricing; I expect that articles published in the past few years could have a larger dataset to be based on. I found out that this inference holds fewer times than I expected. My sample is made of both peer-reviewed articles and grey literature. I also take into account simulations and forecasting models. The great majority of the papers focus on what if instead of what is. It should be stressed that these prospective evaluations make up the great majority of the quantitative literature on carbon pricing, due to the scarcity of data. After this initial screening and an in-depth one for the references in the articles, I created my sample of 12 papers. I only consider studies on the efficacy of carbon pricing; literature on distributional impacts, impacts on technological change, and papers describing the current state of carbon pricing around the world are not included because they are beyond the scope of this review.

2.2 Literature review

It is a fact that the number of countries that are implementing carbon pricing practices has grown rapidly in the last few decades. The reasons behind this phenomenon can be motivated by two main elements: the necessity to achieve the Paris Agreement's goals and the fact that a large branch of the literature considers carbon pricing as an optimal way to diminish emissions (two examples are Parry *et al.*, 2021; Dorband *et al.*, 2019). Despite this, the biggest problem that economists face when they want to assess the effectiveness of carbon pricing policies is related to the short sample that they have to work with and the challenge of detecting CO2 emissions in a precise way. Green (2021) remarked on these problems in her meticulous review of ex-post analyses, demonstrating how all the studies she evaluated have data that never goes beyond 2018 and often have in their datasets either fewer than 10 years of observations or deal with only one country. These factors influenced the conclusion of her review, stating that carbon pricing has a limited or no impact on emissions, with a small amount of research observing the policy's real effects on CO2 reductions. Nevertheless, most of the new studies, with larger and more accurate datasets, are assessing how important carbon pricing is to tackling climate change. Best *et al.* (2020) and D'Arcangelo *et al.* (2022) come to a similar conclusion; with their studies, they assess that a carbon price of 10€/tCO2 can lower the emissions by 3-3.7%. Metcalf & Stock (2020), focusing on both carbon taxes and ETS to enlarge their sample, find that a 4-6% reduction is feasible with a 40$/ton CO2 tax covering 30% of emissions. The paper written by Jung & Song (2023) has as a novelty the use in their regression analysis of the Environmental Kuznets Curve (EKC). The EKC model investigates the link between economic growth and environmental deterioration. It implies that when a country's per capita income rises, environmental degradation worsens at first but gradually improves. As a result, they conclude that jurisdictions with ETSs have a faster reduction, demonstrating its use for long-term development. In addition to the literature using panel data and regression analysis, new studies have also begun to use the VAR and SVAR models. Among them, the paper written by Känzig (2022) is the most interesting one. According to it, a stronger carbon pricing system leads to a considerable increase in energy prices, a sustained drop in emissions, and an increase in green innovation. These indirect effects, which include the higher energy share of poorer households, account for over 80% of the aggregate effect on consumption. Yao *et al.* (2023) are the first (at least to my knowledge) to investigate the connection between ETS and ESG scores. Their findings show that the implementation of China-ETS resulted in improved green governance practices across Chinese firms. Table 2.1 provides a summary of the papers that i found most valuable.

Table 2.1: Summary of papers reviewed

Author (date)	Time period	Jurisdiction	Methodology	Results
Best *et al.* (2020)	1997-2017	142 countries	Panel data with fixed effects	An additional euro per tonne of CO2 in carbon price is associated with a reduction in the subsequent annual emissions growth rate of approximately 0.3 percentage point.

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Table 2.1 (continued)

Author (date)	Time period	Jurisdiction	Methodology	Results
D'Arcangelo *et al.* (2022)	not specified	44 OECD countries	Panel data and dynamic simulation	A 10€ increase in carbon price reduces long-term CO2 emissions from fossil fuels by 3.7%. Extending pricing to unpriced emissions accounts for two-thirds of the effects on emissions and income. Strong carbon rates alone will not reach net-zero emissions; diversified measures such as broader pricing, higher rates, and renewable energy are required.
Dechezlepretre *et al.* (2022)	2005-2012	EU-ETS	Matching methodology with Difference in Difference	EU-ETS reduced emissions by 10% between 2005-2012. Little impact on profits and employment, but an increase in revenues and assets. After 2005, emissions from non-ETS installations surpassed ETS ones.

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Table 2.1 (continued)

Author (date)	Time period	Jurisdiction	Methodology	Results
Dolphin *et al.* (2019)	1990-2015	124 countries	Panel data with fixed effects	Carbon pricing schemes are frequently characterised by lower-than-expected carbon prices, suggesting their weakness. Political and economic forces influence its execution, and policy rigidity progressively emerges. If political limits remain, climate policies must include a variety of methods.
Green (2021)	1990-2020	Global	Systematic review with snowball approach	Carbon pricing have a limited impact on emissions, with only a small number of studies assessing the actual effects of the policy on emissions reductions.

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Table 2.1 (continued)

Author (date)	Time period	Jurisdiction	Methodology	Results
Jung & Song (2023)	1960-2020	26 countries	Panel data with Environmental Kuznets Curve (EKC) tests	Adoption of ETSs is beneficial to both post-industrial and pre-industrial economies. Decoupled countries with ETS show faster reductions, while non-decoupled countries with ETS show slower reductions. ETS considerably reduces carbon emissions per capita, surpassing circumstances such as oil shocks, demonstrating its usefulness for long-term development.
Känzig (2022)	2005-2018	EU-ETS	High-frequency identification and VAR	Carbon pricing increases energy prices, reduces emissions, and encourages green innovation. Higher energy costs have a greater impact on poorer households' consumption. Policy trade-off: redistributing carbon revenues curbs consumption but slightly reduces emission cuts.

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Table 2.1 (continued)

Author (date)	Time period	Jurisdiction	Methodology	Results
Lovcha *et al.* (2022)	2011-2019	EU-ETS	SVAR	Empirical data show that, after accounting for supply factors, carbon price movements are primarily related to market fundamentals, accounting for 90% of fluctuations. Overall, this indicates that ETS functioning is effective.
Metcalf & Stock (2020)	1990-2018	EU-ETS	Panel data and SVAR	There is no consistent negative impact on GDP or employment growth. Little to no positive GDP and employment benefits. 4-6% reduction with a 40$/ton CO2 tax covering 30% of emissions. A larger carbon tax in the United States may produce bigger reductions due to sectoral disparities in marginal abatement costs in Europe.

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Table 2.1 (continued)

Author (date)	Time period	Jurisdiction	Methodology	Results
Osorio *et al.* (2021)	2018-2058	EU-ETS	modelling techniques (LIMES-EU)	Changes in MSR main factors result in cancellations ranging from 2.6-7.9 Gt, compared to 5.1 Gt under present norms. Changing the linear reduction factor (LRF) might help meet ambitious climate targets. Raising LRF to 2.6% in order to meet the EU's -55% objective by 2030 might result in up to 10.0 Gt of cancellations.
Rafaty *et al.* (2020)	1990-2016	39 countries	Panel data and simulations	Carbon pricing reduced CO2 emissions increase by 1% to 2.5%, particularly in electricity and heat sectors. Each $1/tCO2 increase reduced emissions growth by 0.01%. Carbon prices alone, at the global level, may not be enough to meet the Paris climate targets; other non-pricing actions are required.

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Table 2.1 (continued)

Author (date)	Time period	Jurisdiction	Methodology	Results
Yao *et al.* (2023)	2007-2019	China	Panel data with Difference in Difference and Propensity Score Matching	The carbon trading system in China improves corporate green governance. Pilot enterprises dramatically enhance their green governance as a result of ETS, which is driven by government pressure and clean innovation. Bigger, non-state-owned firms benefit the most from green governance.

Overall, the majority of these papers emphasize the effectiveness of carbon pricing schemes in reducing emissions and achieving environmental goals. Some of them observe the necessity for complementing non-pricing polices to fully realise emission reductions in accordance with larger climate agreement and targets (Best *et al.* (2020); Dolphin *et al.* (2019); Rafaty *et al.* (2020)). It has been recognised that carbon pricing has a positive impact not only on the reduction of CO2 but also on innovation, green governance, and overall environmental performance (Känzig (2022); Yao *et al.* (2023)).

More in detail, Best *et al.* (2020) conducted an empirical investigation across many countries to evaluate the efficacy of carbon pricing as a means of mitigating national CO2 emissions generated by fuel combustion. This study places emphasis on the significance of strong policies in addressing the reduction of GHG emissions and using carbon pricing as a pivotal tool to do that. Acknowledging previous individual case studies, such as the one conducted in Sweden, this research emphasises the limited availability of comprehensive international investigations that examine the impacts of carbon pricing on a national level. In order to address this disparity, the researchers use a longitudinal dataset that encompassed 142 nations for a period of two decades.

They carefully accounted for relevant aspects and regulations, utilising econometric modeling methods to assess the impact of carbon pricing. They also took into consideration other policies, such as renewable portfolio standards and fossil fuel subsidies. The study provides a comprehensive analysis of the conceptual underpinnings of carbon pricing, emphasising its capacity to compel polluters to internalise external costs and promote the reduction of emissions through market-based mechanisms. The results demonstrate a significant inverse correlation between carbon pricing and the following growth rates of CO2 emissions. This suggests that for every extra euro per tCO2 in carbon price, there is a notable drop of 0.3 percentage points in the yearly growth rates of emissions. The observed impact exhibits both statistical significance and substantial amplitude, indicating that a 10€ increment in the effective carbon pricing rate would result in a noteworthy reduction of 3 percentage points in the annual growth rate of emissions. Moreover, the research highlights that both carbon taxes and emissions trading systems (ETS) have similar effects on reducing emissions, since their coefficients show no statistically significant disparities.

Dolphin *et al.* (2019) in the first part of their research, draws attention to the puzzling occurrence of below-average carbon prices in countries that expressly implement carbon pricing schemes. The authors analyse the political and economic aspects that have an impact on the implementation and effectiveness of carbon pricing schemes. By doing so, they highlight two crucial policy consequences. The effective implementation of carbon pricing legislation is contingent upon either providing compensation to existing sectors with high carbon emissions or reducing their relative importance. This acknowledgement highlights the political dynamics associated with the successful implementation of carbon pricing mechanisms. Furthermore, the article cautions that the persistence of political economy restrictions may require the implementation of many policy instruments in order to effectively address climate change mitigation. This underscores the importance of adopting a comprehensive and diversified strategy. Moreover, this study critically examines the diplomatic achievements of the Paris Agreement while also highlighting legitimate reservations over its effectiveness in addressing environmental issues. The submission of intended Nationally Determined Contributions (INDCs) under the framework of this international agreement is anticipated to result in increased levels of GHG emissions. In order to comprehensively analyse the complex interplay of political and economic factors that shape carbon pricing, the authors utilise a panel analysis methodology. This technique involves studying a range of national and subnational jurisdictions within North America. They introduce the concept of emissions-weighted carbon price (ECP), a metric designed to measure the stringency of carbon pricing policies. The ECP takes into account the extent to which emissions are included as a fraction of the overall emissions, offering a more comprehensive assessment of the rigor of a policy. Regression models, such as the Heckit technique, are utilised in order to evaluate the likelihood of policy adoption and its underlying causes. These models are employed to examine hypotheses pertaining to regulatory capture and the many influences on the formulation of carbon pricing policies. The study provides significant contributions to the understanding of the political and economic factors that influence the implementation of carbon pricing.

Yao *et al.* (2023) focus on the consequences of China-ETS on company green governance, specifically highlighting Environmental, Social, and Governance (ESG) performance. Using panel data that includes China's A-share listed companies from 2007 to 2019, this study employs the Difference-in-Differences (DID) approach to evaluate the differences in ESG performance between carbon trading enterprises that participated in the pilot programme and those that did not. The dataset extensively utilises the Bloomberg ESG Database for measures related to ESG performance. Furthermore, supplementary variables at the company level are obtained from the Wind and CSMAR databases. Regional data predominantly derives from China's province statistics yearbooks. In order to mitigate the possible influence of estimation bias, the study incorporates the Propensity Score Matching (PSM) technique with the DID approach. This combination ensures that the control and treatment groups possess comparable features prior to the implementation of the policy. The study's findings shed light on the positive impact of China-ETS on the implementation of environmentally responsible practices within corporate governance. The ETS plays a significant role in improving the environmental governance practices of participating companies, encouraging them to meet their ESG responsibilities. The observed beneficial effects can be linked to increased regulatory pressure imposed by the government and the promotion of clean innovation inside firms. Additionally, the research highlights that the efficacy of the ETS is influenced by factors such as ownership and scale, wherein non-state-owned and bigger firms have a more favorable performance in terms of green governance. Moreover, the impact of carbon trading policy is significantly influenced by the amount of marketization at the regional level. Increased marketization enhances the effectiveness and influence of the carbon trading policy. The paper emphasises the need to comprehend the innovative compensation effect of environmental policies, ensure the efficient implementation and oversight of carbon trading regulations, promote the development of green technology, and carefully consider the unique characteristics of enterprises within the carbon trading framework.

Regardless of the strategies and methodologies used to study carbon pricing, these papers share limitations that seem to affect all the literature in this field. They frequently exhibit a common limitation of not explicitly addressing potential shortcomings in their research methodologies or approaches, leaving room for possible biases or weaknesses (Best *et al.* (2020); D'Arcangelo *et al.* (2022); Dolphin *et al.* (2019); Metcalf & Stock (2020)). The generalizability of findings is a recurring constraint, with the main focus frequently being on specific countries or regions, industries or procedures that may not be quickly applicable to other contexts (Dechezlepretre *et al.* (2022); Känzig (2022); Osorio *et al.* (2021); Yao *et al.* (2023)). Another shared issue is the studies' reliance on certain data sources or panel data covering restricted time periods, which could hamper their ability to capture more recent trends (D'Arcangelo *et al.* (2022); Jung & Song (2023);Metcalf & Stock (2020); Osorio *et al.* (2021)). Some studies stand out for the absence of a detailed assessment of potential endogeneity concerns or alternative explanations for observable effects (Best *et al.* (2020); Dolphin *et al.* (2019); Rafaty *et al.* (2020)). The last reoccurring problem is the absence of significant evaluation for data source reliability along with associated measurement biases (Dolphin *et al.* (2019); Metcalf & Stock (2020)).

My primary objective in this study is to evaluate the EU-ETS's effectiveness in reducing CO2 and N2O emissions, a GHG overlooked by existing studies. In addition, I want to verify the influence of the EU-ETS on business ESG ratings, which hasn't been adequately investigated yet. The focus is on EU-ETS Phase 3 (where auctions become the default method for the sale of allowances) and the beginning of Phase 4, enhancing price accuracy. I use a dataset with consistent control variables to try to overcome constraints present in previous studies. Through regression analysis, I aim to point out the relationship between emissions and ESG ratings, potentially revealing correlations between emission cuts and higher ESG scores. I undertake thorough panel data analysis following established methodologies.

In conclusion, the literature that has been examined offers significant contributions to the field of carbon pricing, ETS, and their substantial influence on environmental and economic dynamics. While acknowledging the advancements achieved in comprehending these dynamics, it is evident that the effective implementation of carbon pricing relies not only on the formulation of policies but also on the interaction of political, economic, and institutional elements. Future research efforts should persist in investigating carbon pricing, looking for novel methodologies, and using newly available data to better estimate the effects of these policies.

3. Data and Identification Strategy

This section provides a detailed overview of the variables present in the dataset that I use in the study. The dataset contains environmental, economic, and market variables selected from the papers reviewed, as well as some selected by me personally. [1]

Overall, the panel dataset contains records for 29 countries across 36 quarters (from the beginning of 2013 to the end of 2021), for a total of 1,044 observations for each variable. The dataset presents missing observations only in the variable ”Median E Score” for particular countries and quarters because E scores were not available. The three main sources of data are the Emissions Database for Global Atmospheric Research (EDGAR) for GHG emissions, the European Energy Exchange (EEX) for data related to the auctions of allowances, and the Statistical Office of the European Communities (EUROSTAT) for dependent and control variables. [2]

3.1 Variable description and sources

Country: The countries included in the dataset are the EU-27 members (Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden), plus Iceland and Norway. I exclude Lichtenstein, the 30th member of the EU-ETS, because its emissions are not present in the dataset used.

CO2 and N2O: Total amount of emissions of CO2 and N2O in kilotons for each country in the dataset. The original dataset is the Emissions Database for Global Atmospheric Research (EDGAR), release EDGAR v7.0 (1970 - 2021) of September 2022. Monthly data is aggregated into quarterly.

Price of Allowances: Price for one ton of GHG emission. It is a weighted average of the

[1] N2O, the median Environmental score was never used in the literature.

[2] Other relevant sources for each variable are provided in the next paragraph

auction price for each auction over the volume of allowances auctioned. Weekly data is aggregated into quarters. The data comes from the European Energy Exchange (EEX) which is the platform authorised by the EU to sell the allowances by auction.

N. Allowances: Number of allowances sold at every auction by EEX. We do not know in which state these allowances will be used. This may affect our analysis because we do not have allowance data broken down by country. Weekly data is aggregated into quarters.

Free Allowances: Number of allowances given for free to each country, provided by the Eurpean Environment Agency (EEA). Annual data is divided by four to create quarterly data.

GDP: Gross domestic product at market prices for each country. Current prices in millions of euros, unadjusted data (i.e. neither seasonally adjusted nor calendar adjusted data). Provided by EUROSTAT directly into quarters for each country.

INFL: Inflation, Harmonised Indices of Consumer Prices (HICPs). Annual data is repeated for every quarter of the given year. Unit of measure: Annual average rate of change. Provided by EUROSTAT directly into quarters for each country.

Trade balance: External balance of goods and services. Current prices in millions of euros, unadjusted data (i.e. neither seasonally adjusted nor calendar adjusted data). Provided by EUROSTAT directly into quarters for each country.

Percentage renewable: Percentage of Renewable energy sources. Provided by EUROSTAT with an annual time frequency for each country.

TTF: index for the price of natural gas. Prices are provided by the Nasdaq database. Daily frequency is aggregated into quarters.

Brent: index for the price of crude oil. Prices provided by the Nasdaq database. Daily frequency is aggregated into quarters.

Population: Total population national concept for each country. Provided by EUROSTAT directly into quarters for each country.

Employment: Total employment national concept for each country. Provided by EUROSTAT directly into quarters for each country.

RetStoxx600: Return from an investment of 10.000 euros in the STOXX 600, stock index composed of 600 of Europe's largest market capitalizations. Value taken at the end of each quarter. The source is Yahoo Finance.

Median E score: Median of the Environmental score given by MSCI to companies in the countries analysed. Monthly data is aggregated into quarters. Source: ESG scores from MSCI provided by Pr. Boccaletti, within its research project on sustainable finance under the O-Fire Lab.

Carbontax: dummy variable =1 if the country at the given date presents an additional carbon tax/ETS different from the EU-ETS. The source is the carbon pricing dashboard by the World Bank.

3.1.1 Descriptive statistics and correlation

In this section, I analyse relevant descriptive statistics for the variables used and the correlation between them. The tables are provided below.

Overall, Germany is the country that emits the most, with CO2 and N2O emissions that are respectively 9.50 times and 4.75 times higher than the average. Germany is also the nation that receives the majority of free allowances, while Malta never receives them. The average price for the allowances in the periods analysed is 16.28€/tCO2. The price started to increase constantly after the introduction of the MSR in January 2019, reaching its peak in the last quarter of the dataset, with a price slightly below 67€/tCO2. Regarding the proportion of renewable energy, we can observe that the average for Europe is one-fourth of all energy consumed. The largest percentage is in Iceland, where in 2021 more than 85% of energy come from renewable sources (mainly geothermal and hydropower).On the other side, Luxembourg in 2013 had the lowest proportion, at 3%.

From Table 3.2, it is evident how closely connected the examined GHGs' emissions are. There is a strong positive correlation between CO2 and N2O, as well as GDP, population, and employment, confirming that emissions are intrinsically linked to economic growth. Free allowances have a strong and positive relationship with GHGs too, demonstrating that when companies do not have to pay, they pollute more. The positive and significant relationship between free allowances and GDP reinforces this statement. Trade balance also has a significant positive correlation with

Table 3.1: Descriptive Statistics for Key Variables

Variable	Mean	S.D.	Min	Max
CO2 Emissions	31703.79	45647.33	321.6401	301452.3
N2O Emissions	7.370251	8.749352	.0366545	34.95553
Price of Allowances	16.277	15.5639	3.802439	66.9928
N. Allowances	165000000	34200000	90000000	218000000
Free Allowances	6410591	8313285	0	42400000
GDP	115137	184028.4	1841.3	947720
INFL	1.212644	1.310929	-1.7	5.2
Trade Balance	4539.026	11192.1	-39248.3	68343
Percentage Renewable	25.10852	17.51961	3.494	85.785
TTF (Gas Price Index)	8.213889	6.201301	1.65	37.36
Brent (Oil Price Index)	66.44667	23.69071	14.85	111.03
Population	15565.14	21308.32	322.9	83283
Employment	7095.383	9952.786	163.1	45432
Return STOXX600	17856.89	3378.815	11977	26646
Median E Score	5.818982	1.217645	1.9	10
Carbontax	.4099617	.492062	0	1

CO2, N2O and the number of allowances given for free. This relationship suggests that export-oriented economies may also participate more in carbon-intensive manufacturing processes and receive more allowances for free. Moreover, there are several significant links between the price of allowances that should be addressed. In fact, the cap-and-trade system has been proven to work once more, since the price rises as fewer allowances are made available (both auctioned and free ones). There is also a positive association between price and inflation, which is most likely affected by the spike in prices after the COVID-19 pandemic. Furthermore, there is a significant and positive correlation between the price of allowances and STOXX600 returns of 0.88. As expected, there is also a moderate negative correlation between emissions and renewable energy, meaning

Table 3.2: Pairwise correlation matrix

Variables	CO2	N2O	Price	N. Allowances	Free Allowances	GDP	Inflation	Trade Balance	% Renewable	TTF	Brent	Population	Employment	Ret. STOXX600	Median E score	Carbontax
CO2	1.000															
N2O	0.894***	1.000														
Price	-0.026	-0.007	1.000													
N. Allowances	0.020	0.002	-0.170***	1.000												
Free Allowances	0.946***	0.894***	-0.100***	-0.008	1.000											
GDP	0.916***	0.879***	0.042	0.003	0.870***	1.000										
Inflation	0.002	0.011	0.463***	0.198***	-0.044	-0.001	1.000									
Trade Balance	0.651***	0.445***	0.013	0.006	0.617***	0.621***	0.019	1.000								
% Renewable	-0.220***	-0.254***	0.095***	-0.003	-0.241***	-0.168***	0.156***	-0.146***	1.000							
TTF	0.002	-0.001	0.536***	-0.175***	-0.011	0.014	0.288***	0.000	0.012	1.000						
Brent	-0.001	-0.002	-0.057*	-0.012	0.056*	-0.015	0.179***	-0.006	-0.045	0.451***	1.000					
Population	0.930***	0.942***	0.002	0.000	0.911***	0.945***	-0.024	0.507***	-0.246***	0.000	-0.002	1.000				
Employment	0.956***	0.932***	0.014	0.002	0.932***	0.965***	-0.005	0.592***	-0.234***	0.001	-0.007	0.989***	1.000			
Ret. STOXX600	-0.021	-0.004	0.880***	-0.022	-0.112***	0.046	0.439***	0.024	0.094***	0.330***	-0.240***	0.003	0.016	1.000		
Median E score	-0.078**	-0.052	-0.028	0.016	-0.104***	-0.005	0.021	-0.057*	-0.114***	0.025	-0.011	-0.041	-0.037	0.004	1.000	
Carbontax	-0.044	0.104***	0.012	-0.008	-0.057*	-0.010	0.019	-0.102***	0.509***	-0.007	-0.027	-0.021	-0.048	0.023	-0.158***	1.000

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

that the more clean energy a country uses, the less it pollutes. Carbon taxes have a notable positive relation with the share of renewable energy. This supports the theory that carbon pricing can motivate emission reductions by making high-carbon activities more expensive and speeding up the transition to renewable sources. Notwithstanding, it appears to have little to no impact on CO2 and a negative and significant influence on the median E scores. To conclude, I want to point out that while the median E score grows as CO2 emissions decrease significantly, the median has a significant negative relationship with the share of renewable energy. This result is contradictory, and future research should look at this kind of link more thoroughly.

3.1.2 Limitations

The limitations that might affect my analysis and the estimations are related to three main issues. First, the missing breakdowns of allowances sold by nation might affect the precision of country-level analysis. The revenue that each nation received from the sale of allowances might have been used to analytically address this issue. However, EEX only provides this data in some of its annual reports. This would eventually have resulted in a large number of missing variables that would have impacted the outcomes in any case. Second, some variables are taken from aggregated data, as mentioned in Section 3.1, which may impact the findings' granularity. A key example of this is the percentage of renewable energy available only with an annual time frequency. Third, the fact that the median E score is calculated taking into account all the companies rated by MSCI in the countries present in the dataset. This approximation was necessary since there is not a comprehensive list of the firms that are obliged to participate in the auctions.

3.2 Identification Strategy

My analysis consists of two main steps: the first is to assess the efficacy of the EU-ETS in reducing GHG emissions; the second is to understand the relationship between the EU-ETS and the E scores of European companies. If the rationale behind the first test is evident, given the nature of the EU-ETS, the logic behind the second test has to be elucidated. In fact, if the ETS is truly encouraging firms to become more environmentally friendly, this should result in a rise in E ratings for companies. To test both of my hypotheses, I conducted a regression analysis with fixed effects (for countries and time) using Stata. Fixed effects are a standard regression technique that can be used to control for unobserved heterogeneity between subjects. This can be important in cases where the unobserved heterogeneity is correlated with the independent variables, as it can lead to biased estimates of the model coefficients. They are widely used in economics papers, as seen in the literature review. I also adopt Generalised Method of Moments (GMM) models to deal with endogeneity and serial correlation in my panel dataset. It provides a method for estimating dynamic relationships, capturing how past values of variables impact the present, including lags of endogenous variables, by employing lagged dependent variables as instruments.

3.2.1 Testing the efficacy of EU-ETS

The two general model specifications for my regression analysis are the following :

$$\begin{aligned} y = \beta_0 + \beta_1 Price + \beta_2 N.Allowances + \beta_3 FreeAllowances \\ + \beta_4 GDP + \beta_5 TradeBalance + \beta_6 TTF + \beta_7 Brent \\ + \beta_8 \%Renewable + \beta_9 Employment \\ + \gamma_{\text{Country}} + \delta_{\text{Quarter}} + \varepsilon \end{aligned} \tag{3.1}$$

$$\begin{aligned} y = \beta_0 + \beta_1 Price + \beta_2 N.Allowances + \beta_3 GDP + \beta_4 TradeBalance \\ + \beta_5 Brent + \beta_6 Population + \beta_7 Employment + \beta_8 Ret.Stoxx600 \\ + \beta_9 CarbonTax + \gamma_{\text{Country}} + \delta_{\text{Year}} + \varepsilon \end{aligned} \tag{3.2}$$

Tables 3.3 to 3.5 report the findings related to the first model specification, where the dependent variables are CO2 per capita and N2O per capita. The fixed effects are for countries and quarters. From Table 3.6 to Table 3.8, I report the findings for the second specification of the model, in which the dependent variables used are CO2 per GDP and N2O per GDP. This ratio is commonly used to understand the emissions produced per unit of economic output and to assess the carbon intensity and efficiency of an economy. The fixed effects are for countries and years.

Table 3.3: The Effect of EU-ETS on CO2 and N2O per capita

	Dependent Variable	
	CO2 per capita	N2O per capita
Price	-0.9790***	-0.0754
	(0.0826)	(0.2170)
N. Allowances	0.3930***	0.0782
	(0.0534)	(0.1400)
Free Allowances	-1.5200***	1.3100
	(0.4810)	(1.2700)
GDP	-1.2800**	-7.3500***
	(0.0516)	(1.3600)
Trade Balance	0.4920***	0.9470
	(0.1270)	(3.3500)
TTF	0.1400***	2.6400
	(0.0141)	(3.7000)
Brent	-0.1270***	-2.9700
	(0.0136)	(3.5800)
% Renewable	-0.2990***	0.8760
	(0.0484)	(1.2700)
Employment	2.8670***	-0.6280***
	(0.6790)	(0.1780)
Constant	8.561***	0.8370***
	(0.5750)	(0.1510)
Observations	1,044	1,044
Fixed Effects	yes	yes
R^2	0.952	0.969

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

Table 3.3 shows that the EU-ETS is actually having an impact on CO2 but not on N2O. All the coefficients for CO2 per capita are statistically significant at 1% level, except the GDP, which is at 5%. The negative coefficient for the price indicates that as polluting becomes more expensive, CO2 emissions per capita decrease significantly. The coefficient for the number of allowances is positive, indicating that an increase in allowances leads to an increase in CO2. On the other side, the coefficient for free allowances is negative, implying that as the number of free allowances increases, CO2 emissions per capita decrease. This finding suggests that giving allowances for free is still necessary to promote the functioning of the ETS, even after the end of the pilot and second phase of the EU-ETS, where most of them were given for free. The coefficients for TTF and Brent are both significant at 1% level, but they have opposite signs. If it is easy to understand that a rise in price leads to a reduction in use and hence a reduction in emissions for Brent, this intuition does not apply for TTF since TTF prices are always lower than those for Brent in my dataset. Looking now at the control variables, the results are quite consistent with what we can expect; having a positive trade balance implies higher emissions as well as a higher employment rate. The percentage of renewable energy available is also a key player in reducing emissions, as shown by the negative sign of the coefficient. The GDP coefficient is the only one that might look ambiguous. In fact, an increase in GDP appears to result in a drop in CO2 per capita. This statement, however, is consistent with the findings of Jung and Song (2023) for European countries. Moving to the results for the N2O, we can see that only two variables are significant: GDP, from which the previous statement can be applied, and employment. For this one, it seems that an increase in employment decreases the emission of N2O. This relation needs to be further investigated to understand the reason behind it.

Introducing a one-period lag to my previous regression yields the results shown in Table 3.4. For Column (CO2 per capita) the price for allowances is still negative, but it loses significance from 1% to 10%. Its coefficient saw a reduction of more than two-thirds with respect to the previous one. Free allowances also saw a reduction in significance, but the coefficient increased. The GDP coefficient turns positive but becomes significant only at 10% level. It is noteworthy to observe how the coefficients for trade balance and employment have shifted to a negative sign. These

Table 3.4: The Effect of EU-ETS on CO_2 and N_2O per capita with a GMM

	Dependent Variable	
	CO2 per capita	N2O per capita
Lag	0.7280**	0.7380***
	(0.286)	(0.0203)
Price	-0.3080*	0.5700***
	(0.1720)	(0.1750)
N. Allowances	1.6000***	0.1730
	(0.3190)	(0.3170)
Free Allowances	-2.1600*	0.2260**
	(1.1600)	(0.1070)
GDP	1.9400*	1.6200
	(1.0900)	(1.1400)
Trade Balance	-0.4250**	-0.7420
	(0.1830)	(1.7900)
TTF	0.1260***	-0.1130
	(0.0259)	(0.2580)
Brent	-0.3320***	-2.3600***
	(0.0560)	(0.5580)
% Renewable	-0.2970***	-0.1500*
	(0.0744)	(0.0780)
Employment	-6.0550***	-0.3200***
	(0.9210)	(0.0963)
Constant	5.4900***	0.3120***
	(0.4950)	(0.0517)
Observations	986	986
Fixed Effects	yes	yes
χ^2	211.09	1545.81

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

changes can be motivated by the lagged effects that normal OLS regression could not capture or by the fact that GMM regression better captures the true effect of the independent variables, correcting endogeneity. Moving to the second column (N2O per capita), the results are still puzzling and unclear. The price becomes significant at 1% level but the coefficient is positive, suggesting that an increase in the price of the allowances is associated with higher N2O emissions. This finding contradicts every evidence in the literature, and so I do not believe it should be taken into account. Free allowances become positive and significant, indicating that an increase in free allowances is associated with higher N2O emissions per capita. The coefficient for employment halved in size but remained negative and significant. Overall, also in Table 3.4, we see how the EU-ETS seems to have the desired effects on CO2 but not on N2O.

In Table 3.5, I analyse the change in emissions between one quarter and the previous one in order to determine how much of this variation can be explained by the EU-ETS. In this case, for both GHG the number of allowances is positive and significant, indicating that an increase in allowances is associated with an increase in the variation of emissions. For CO2, this effect is significantly larger with respect to N2O. Trade balance shows a negative and significant coefficient, suggesting that a more negative trade balance is associated with a decrease in emissions. The R-squared values show that the ΔCO2pc model explains a large proportion of the variation in CO2 emissions changes, around 76%, while the ΔN2Opc model explains only the 22.9% of the variation in N2O emissions.

Table 3.5: The Effect of EU-ETS on the variation of CO2 and N2O per capita

	Dependent Variable	
	ΔCO2pc	ΔN2Opc
Price	-0.0820	-0.0154
	(0.2240)	(0.0288)
N. Allowances	0.8260***	0.0031**
	(0.1170)	(0.0015)
Free Allowances	2.7500	-0.3780
	(5.5500)	(0.7130)
GDP	4.9200	-0.0601
	(6.1800)	(0.0795)
Trade Balance	-0.5720***	-0.3250*
	(0.1460)	(0.1880)
TTF	0.8170***	0.2850***
	(0.0568)	(0.0730)
Brent	-0.2510***	-0.0945***
	(0.0184)	(0.0237)
% Renewable	-0.1810	0.0003
	(0.5700)	(0.7320)
Employment	-1.0850	0.0333
	(0.7890)	(0.1010)
Constant	0.0704	-0.1930
	(0.5410)	(0.6960)
Observations	1,015	1,015
Fixed Effects	yes	yes
R^2	0.761	0.229

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 3.6: The Effect of EU-ETS on CO_2 and N_2O per GDP

	Dependent Variable	
	CO2perGDP	N2OperGDP
Price = L,	-0.2480***	-0.0411***
	(0.0848)	(0.0130)
N. Allowances = L,	-5.1100***	-2.9400
	(1.2100)	(1.8700)
GDP = L,	4.0200***	4.9200***
	(0.5270)	(0.8110)
Trade Balance = L,	-5.8400	-0.1550
	(8.2200)	(1.2600)
Brent = L,	0.5740	1.1000
	(0.4820)	(0.7410)
Population = L,	0.2370**	0.8470***
	(0.1040)	(0.1600)
Employment = L,	-0.1140***	-0.3970***
	(0.0316)	(0.0486)
Ret STOXX600 = L,	-1.7300***	-0.3010***
	(0.4520)	(0.0696)
Carbon tax = L,	-0.1020	0.0522
	(0.7620)	(0.1170)
Constant	-2.5620	-0.9320***
	(1.5880)	(0.2440)
Observations	1,015	1,015
Fixed Effects	yes (combined)	yes (combined)
R^2	0.905	0.982

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

The results in Table 3.6 investigate more in detail how lagged variables affect my variables of interest. It presents strong evidence that past values for variables related to the EU-ETS impact both CO2 and N2O emissions in the following period. I find a significant negative relationship between lagged prices and CO2 emissions per GDP, implying that higher past prices for allowances are associated with lower emissions. This holds for both CO2 and N2O, but for the latter, the coefficient is smaller. The number of allowances presents a negative coefficient for both specifications, but it is significant only for CO2 per GDP. This means that higher lagged allowances are associated with lower CO2 emissions. The GDP coefficients are positive and significant at 1% level, demonstrating that higher past GDP levels are associated with larger emissions per GDP. The positive and significant relationship for population shows that higher population at t-1 is associated with increased emissions at time t for both gases. Interestingly, higher past employment levels are linked to lower emissions per GDP. This finding can be related to macroeconomic business cycles. Moreover, higher past returns for STOXX600 are associated with lower CO2 and N2O emissions per GDP. Further investigations are necessary to understand these two phenomena. The R-squared for the two models is above .90, and they are comparable with the ones in Table 3.3.

Table 3.7 presents the results for the same model specification presented in the previous table but using a GMM with lag 1. The results are comparable to the previous findings. The difference is that in this case, the number of allowances is significant for N2O per GDP, indicating that higher lagged allowances lead to lower emissions. Lagged Brent prices have a significant positive relationship with CO2 emissions per GDP, meaning that higher historical Brent crude oil prices are related to greater CO2 emissions per GDP. This is in contrast to the previous findings. It is interesting to see that, even if the carbon tax dummy variable is not significant, the coefficient is negative, meaning that carbon taxes are negatively related to emissions.

Table 3.8 shows the change in emissions between one quarter and the previous one in order to determine how much of this variation can be explained by the EU-ETS. Price in this specification becomes positive,indicating that higher past prices are associated with an increase in the difference of CO2 and N2O per GDP. The allowances lose significance, and the coefficients for GDP turn negative, suggesting that higher past GDP levels are linked to a decrease in the difference

Table 3.7: The Effect of EU-ETS on CO_2 and N_2O per GDP with GMM

	Dependent Variable	
	CO2perGDP	N2OperGDP
Lag	0.1370***	0.3060***
	(0.0284)	(0.0289)
Price = L,	-0.3260***	-0.0361***
	(0.0442)	(0.0079)
N. Allowances = L,	-5.9000***	-7.6500***
	(0.8720)	(1.5500)
GDP = L,	2.5200***	2.8700***
	(0.3770)	(0.6850)
Trade Balance = L,	-1.0700	-0.0841
	(6.6400)	(0.1150)
Brent = L,	0.4730***	-0.0013
	(0.1310)	(0.0234)
Population = L,	7.2700***	2.8900***
	(2.3500)	(0.4380)
Employment = L,	-8.1300***	-0.2670***
	(2.3200)	(0.0409)
Ret STOXX600 = L,	-4.1500**	-0.1020***
	(2.0600)	(0.0371)
Carbon tax = L,	-0.0516	-0.1250
	(0.0793)	(0.1370)
Constant	-0.3000	-0.1780***
	(0.3250)	(0.0571)
Observations	986	986
Fixed Effects	yes	yes
χ^2	505.74	266.23

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 3.8: The Effect of EU-ETS on the variation of CO_2 and N_2O per GDP

	Dependent Variable	
	ΔCO2perGDP	ΔN2OperGDP
Price = L,	0.5110***	0.0457**
	(0.1360)	(0.0222)
N. Allowances = L,	0.9000	-3.3600
	(1.6000)	(2.6100)
GDP = L,	-4.7100***	-3.5300***
	(0.7170)	(1.1700)
Trade Balance = L,	0.6040	-0.2970
	(1.1100)	(1.8100)
Brent = L,	-0.1430**	-2.6200**
	(0.0637)	(1.0400)
Population = L,	-0.5520***	-1.3800***
	(0.1410)	(0.2300)
Employment = L,	0.4250***	0.6490***
	(0.0438)	(0.0713)
Ret STOXX600 = L,	2.9100***	4.6100***
	(0.6010)	(0.9800)
Carbon tax = L,	-0.0476	-0.1040
	(0.1010)	(0.1640)
Constant	5.6370***	0.1660***
	(2.1540)	(0.0351)
Observations	986	986
Fixed Effects	yes (combined)	yes (combined)
R-squared	0.273	0.261

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

in emissions per GDP. Brent turns negative and acquires significance, implying that higher past oil prices are associated with a decrease in emissions. The value for population indicates that a higher lagged population is associated with a decrease in Δ CO2 and N2O per GDP, and higher employment at time t-1 is linked to an increase in GHGs at time t. Lastly, higher past returns in the STOXX600 are associated with an increase in variation for both gases.

3.2.2 Assessing the effect of EU-ETS on European firms' E scores

In order to examine the relationship between the E scores of European companies and the EU-ETS, I use the E scores provided by MSCI as the dependent variable. The independent variables consist of data related to GHG emissions, the EU-ETS, as well as conventional economic factors including GDP and employment. Weak and negative correlations can be observed between the E scores and several other factors, namely GHG emissions, price for the allowances, number of free allowances, and share of renewable energy. Positive correlations are observed between E scores and the number of allowances, as well as with the return of STOXX600.

The results reveal no statistically significant relations despite substantial model specification revisions, including the use of lag, the GMM model, and fixed effects for country and time. These results imply that GHG emissions and the EU-ETS do not have a major impact on the E ratings of European enterprises. This lack of statistical significance underscores how complex environmental sustainability in corporate contexts is, as well as the need for more future research and analysis of possibly unaccounted-for factors that might affect E scores. My findings are in contrast with the ones of Yao *et al.* (2023) in the Chinese context. The pressure from the government and company participation in clean innovation played a key role in helping the Pilot-ETS in China achieve their higher ESG scores. It's also important to note that my research found no correlation between the two systems, indicating that an increase in a company's E score is not always a result of a reduction in CO2 emissions among European enterprises. In fact, as illustrated in Figure 3.1, the data show that E ratings were dropping over time, following the trend in emissions. This result highlights once more how difficult it is to assess a company's environmental performance based on emission reduction programmes. More research and in-depth analysis are necessary since other variables, connected to company sustainability plans, reporting procedures, or external influences, may influence E ratings more significantly.

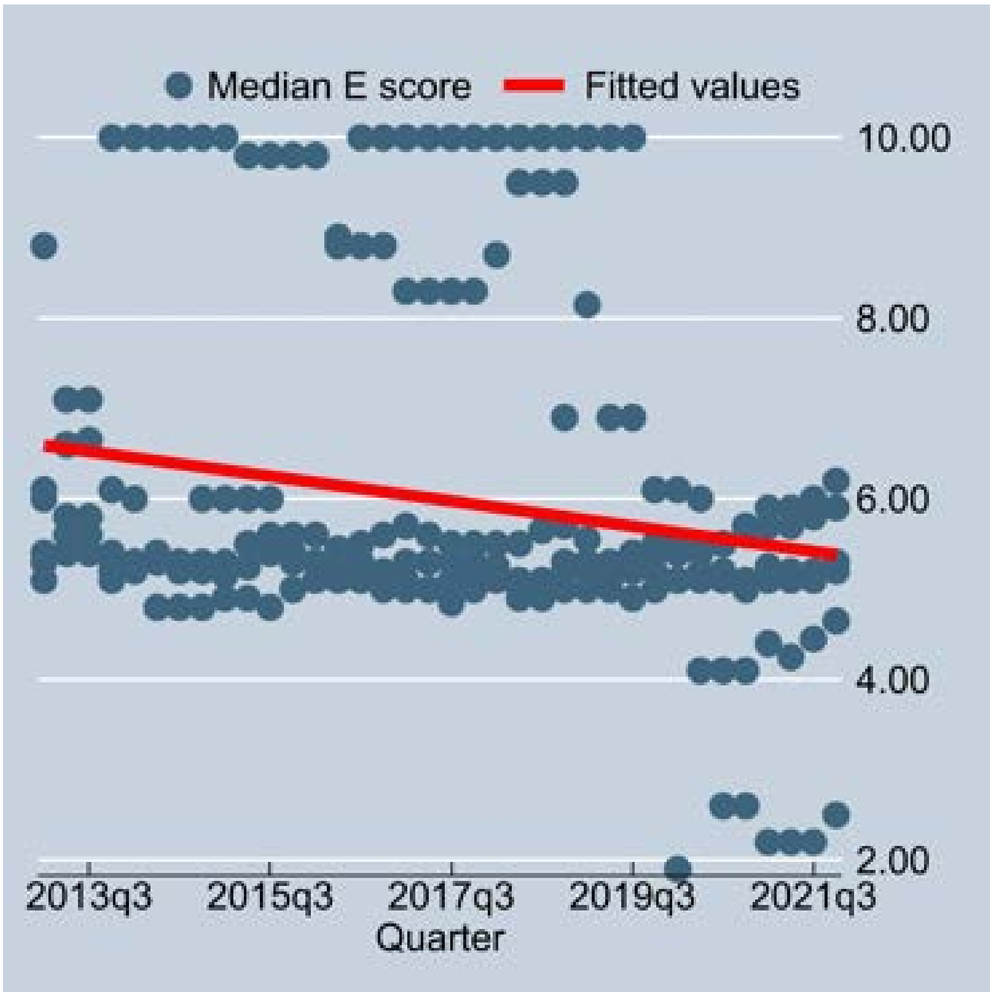


Figure 3.1: Variation of E scores for european companies over the time period analysed

Conclusion

The results obtained from my study provide insights into the effects of the EU-ETS on CO2 and N2O emissions, as well as their interplay with other economic and environmental variables. The study provides evidence that the EU-ETS has noticeable effects on CO2 emissions per capita. The increase in the price of permits allows for a substantial drop in CO2 emissions as the cost of pollution rises. This discovery highlights the efficacy of price schemes in mitigating emissions. Furthermore, a lower number of allowances results in a decrease in CO2 emissions. Nevertheless, the presence of a negative coefficient for free allowances indicates that the provision of free allowances continues to be crucial in facilitating the operation of the EU-ETS, even in the aftermath of the pilot and second phases, where a majority of allowances were supplied without charge. The control variables yield consistent findings, indicating a positive correlation between trade balance and emissions, as well as higher employment rates and emissions. Additionally, a higher proportion of renewable energy sources is shown to be related to a reduction in emissions. The observed correlation between per capita CO2 emissions and GDP is consistent with other study findings.

In contrast to CO2, it seems that the EU-ETS is not having a substantial influence on N2O emissions. The findings of my study indicate that there are statistically significant relationships between the emissions of N2O and two variables, namely GDP and employment. Specifically, a rise in GDP is shown to be positively connected with greater levels of N2O emissions. Conversely, higher rates of employment are found to be negatively linked to N2O emissions, suggesting that increased employment is associated with lower levels of N2O emissions. Further work is necessary to understand the underlying factors contributing to this last connection.

Incorporating lagged effects into the GMM regression framework yields significant insights. There exists a negative association between CO2 emissions and lagged pricing for allowances, indicating that higher historical allowance costs result in reduced emissions. The results are consistent for N2O, but with a smaller coefficient. The findings further underscore the significance of previous values for EU-ETS-related variables in exerting influence on both CO2 and

N2O emissions in succeeding time periods. This statement underscores the need to develop a comprehensive comprehension of temporal impacts. Upon doing an analysis of emissions fluctuations over several quarters, it becomes evident that the quantity of allowances has a beneficial impact on the variability of emissions for both CO2 and N2O. However, this effect is more prominently shown in the case of CO2 emissions. A negative trade balance is correlated with a reduction in emission variability.

The analysis of the correlation between GHG emissions, the EU-ETS, and ESG scores suggests that the EU-ETS has limited to no influence on the E ratings of European firms. This implies that additional variables, such as governmental influence and advancements in sustainable technology, might have increasingly significant influences on the determination of ESG ratings. The results highlight the intricate nature of evaluating environmental sustainability within the business sphere. The lack of a link between the decrease in GHG emissions and ESG ratings underscores the complexity of this topic. The analysis necessitates more investigation to examine undisclosed variables that impact E ratings.

It is important to be aware of the limitations that affect this study. The above-mentioned factors include the lack of detailed categorization of allowances sold on a national level, the effect of aggregated data on the level of detail, and the use of the median E ratings of all the companies rated because of limitations in the data. Future studies should aim to address these constraints in order to enhance the precision and accuracy of the analysis.

In conclusion, this research offers contributions to the understanding of the influence of the European Union Emissions Trading Scheme (EU-ETS) on CO2 and N2O emissions. It highlights the significance of pricing mechanisms, delayed impacts, and the necessity for a more complete comprehension of environmental sustainability within the business sphere. Additional research is required to delve into these challenging relationships and their implications.

List of Figures

Bibliography

AR6 Synthesis Report (2023). *AR6 Synthesis Report: Climate Change 2023*. URL: https://www.ipcc.ch/report/ar6/syr/ (visited on 09/04/2023).

Assessing the Global Climate in 2022 (Jan. 11, 2023). National Centers for Environmental Information (NCEI). URL: https://www.ncei.noaa.gov/news/global-climate-202212 (visited on 08/13/2023).

Best, Rohan, Paul J. Burke, and Frank Jotzo (Sept. 1, 2020). "Carbon Pricing Efficacy: Cross-Country Evidence". In: *Environmental and Resource Economics* 77.1, pp. 69–94. ISSN: 1573-1502. DOI: 10.1007/s10640-020-00436-x. URL: https://doi.org/10.1007/s10640-020-00436-x (visited on 03/05/2023).

Canada, Environment {and} Climate Change (Aug. 5, 2021). *Update to the Pan-Canadian Approach to Carbon Pollution Pricing 2023-2030*. URL: https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/carbon-pollution-pricing-federal-benchmark-information/federal-benchmark-2023-2030.html (visited on 03/15/2023).

Cap-and-Trade Program — California Air Resources Board (2023). URL: https://ww2.arb.ca.gov/our-work/programs/cap-and-trade-program (visited on 03/15/2023).

Chepeliev, Maksym, Israel Osorio-Rodarte, and Dominique van der Mensbrugghe (Oct. 1, 2021). "Distributional impacts of carbon pricing policies under the Paris Agreement: Inter and intra-regional perspectives". In: *Energy Economics* 102, p. 105530. ISSN: 0140-9883. DOI: 10.1016/j.eneco.2021.105530. URL: https://www.sciencedirect.com/science/article/pii/S0140988321004084 (visited on 03/06/2023).

China National ETS — International Carbon Action Partnership (Dec. 2, 2022). URL: `https://icapcarbonaction.com/en/ets/china-national-ets` (visited on 03/15/2023).

Climate Transparency (Aug. 31, 2023). Climate Transparency. URL: `https://www.climate-transparency.org/` (visited on 09/04/2023).

Colmer, Jonathan et al. (2020). "Does Pricing Carbon Mitigate Climate Change? Firm-Level Evidence from the European Union Emissions Trading Scheme". In: *SSRN Electronic Journal*. ISSN: 1556-5068. DOI: `10.2139/ssrn.3725482`. URL: `https://www.ssrn.com/abstract=3725482` (visited on 08/20/2023).

D'Arcangelo, Filippo Maria et al. (Nov. 21, 2022). *Estimating the CO2 emission and revenue effects of carbon pricing: New evidence from a large cross-country dataset*. Paris: OECD. DOI: `10.1787/39aa16d4-en`. URL: `https://www.oecd-ilibrary.org/economics/estimating-the-co2-emission-and-revenue-effects-of-carbon-pricing_39aa16d4-en` (visited on 09/04/2023).

Database - Eurostat (2023). URL: `https://ec.europa.eu/eurostat/web/main/data/database` (visited on 09/04/2023).

Dechezleprêtre, Antoine, Daniel Nachtigall, and Frank Venmans (Mar. 1, 2023). "The joint impact of the European Union emissions trading system on carbon emissions and economic performance". In: *Journal of Environmental Economics and Management* 118, p. 102758. ISSN: 0095-0696. DOI: `10.1016/j.jeem.2022.102758`. URL: `https://www.sciencedirect.com/science/article/pii/S0095069622001115` (visited on 09/04/2023).

Dolphin, Geoffroy, Michael G. Pollitt, and David M. Newbery (2020). "The political economy of carbon pricing: a panel analysis". In: *Oxford Economic Papers* 72.2. Publisher: Oxford University Press, pp. 472–500. URL: `https://ideas.repec.org//a/oup/oxecpp/v72y2020i2p472-500..html` (visited on 09/04/2023).

Dorband, Ira Irina et al. (Mar. 2019). “Poverty and distributional effects of carbon pricing in low- and middle-income countries – A global comparative analysis”. In: *World Development* 115, pp. 246–257. ISSN: 0305750X. DOI: 10.1016/j.worlddev.2018.11.015. URL: https://linkinghub.elsevier.com/retrieve/pii/S0305750X18304212 (visited on 01/25/2023).

EEX EUA Primary Auction Spot - Download (2023). URL: https://www.eex.com/en/market-data/environmental-markets/eua-primary-auction-spot-download (visited on 09/04/2023).

Elements of RGGI — RGGI, Inc. (2023). URL: https://www.rggi.org/program-overview-and-design/elements (visited on 03/15/2023).

EU Emissions Trading System (ETS) data viewer — European Environment Agency (2023). URL: https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1 (visited on 09/04/2023).

EU Emissions Trading System (EU ETS) (2023). URL: https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en (visited on 03/15/2023).

European Commission. Joint Research Centre. (2022). *CO2 emissions of all world countries :JRC/IEA/PBL 2022 report.* LU: Publications Office. URL: https://data.europa.eu/doi/10.2760/730164 (visited on 09/04/2023).

Grafici, dati e notizie su STXE 600 PR.EUR (ˆSTOXX) - Yahoo Finanza (2023). URL: https://it.finance.yahoo.com/quote/%5ESTOXX/ (visited on 09/04/2023).

Green, Jessica F (Apr. 1, 2021). “Does carbon pricing reduce emissions? A review of ex-post analyses”. In: *Environmental Research Letters* 16.4, p. 043004. ISSN: 1748-9326. DOI: 10.1088/1748-9326/abdae9. URL: https://iopscience.iop.org/article/10.1088/1748-9326/abdae9 (visited on 01/25/2023).

Greenhouse gas emission statistics - emission inventories (2023). URL: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Greenhouse_gas_emission_statistics_-_emission_inventories (visited on 07/15/2023).

Ian Parry (2021). *Five Things to Know about Carbon Pricing*. URL: https://www.imf.org/en/Publications/fandd/issues/2021/09/five-things-to-know-about-carbon-pricing-parry (visited on 03/08/2023).

Jung, Hail and Chang-Keun Song (Jan. 17, 2023). "Effects of emission trading scheme (ETS) on change rate of carbon emission — Scientific Reports". In: *Scientific Reports* 13.1, p. 912. ISSN: 2045-2322. DOI: 10.1038/s41598-023-28154-6. URL: https://www.nature.com/articles/s41598-023-28154-6 (visited on 03/18/2023).

Känzig, Diego R. (Jan. 2022). *The unequal economic consequences of carbon pricing*. URL: https://www.bancaditalia.it/pubblicazioni/altri-atti-seminari/2021/Kaenzig_paper.pdf.

Lovcha, Yuliya, Alejandro Perez-Laborda, and Iryna Sikora (2022). "The determinants of CO2 prices in the EU emission trading system". In: *Applied Energy* 305 (C). Publisher: Elsevier. ISSN: 0306-2619. URL: https://econpapers.repec.org/article/eeeappene/v_3a305_3ay_3a2022_3ai_3ac_3as0306261921012162.htm (visited on 09/04/2023).

Makridou, Georgia, Michalis Doumpos, and Emilios Galariotis (June 1, 2019). "The financial performance of firms participating in the EU emissions trading scheme". In: *Energy Policy* 129, pp. 250–259. ISSN: 0301-4215. DOI: 10.1016/j.enpol.2019.02.026. URL: https://www.sciencedirect.com/science/article/pii/S0301421519301090 (visited on 08/20/2023).

Metcalf, Gilbert E. and James H. Stock (July 2020). *The Macroeconomic Impact of Europe's Carbon Taxes*. DOI: 10.3386/w27488. URL: https://www.nber.org/papers/w27488 (visited on 03/07/2023).

Narassimhan, Easwaran et al. (Sept. 14, 2018). “Carbon pricing in practice: a review of existing emissions trading systems”. In: *Climate Policy* 18.8, pp. 967–991. ISSN: 1469-3062, 1752-7457. DOI: 10.1080/14693062.2018.1467827. URL: https://www.tandfonline.com/doi/full/10.1080/14693062.2018.1467827 (visited on 01/25/2023).

Nasdaq Data Link (2023). URL: https://data.nasdaq.com (visited on 09/04/2023).

Nikolov, Plamen (2022). “Writing Tips for Economics Research Papers 2021-2022 Edition”. In: *SSRN Electronic Journal*. ISSN: 1556-5068. DOI: 10.2139/ssrn.4114601. URL: https://www.ssrn.com/abstract=4114601 (visited on 08/13/2023).

Osorio, Sebastian et al. (Nov. 1, 2021). “Reviewing the Market Stability Reserve in light of more ambitious EU ETS emission targets”. In: *Energy Policy* 158, p. 112530. ISSN: 0301-4215. DOI: 10.1016/j.enpol.2021.112530. URL: https://www.sciencedirect.com/science/article/pii/S0301421521004006 (visited on 06/02/2023).

Paddison, Laura (July 5, 2023). *The planet saw its hottest day on record this week. It’s a record that will be broken again and again*. CNN. URL: https://www.cnn.com/2023/07/05/world/hottest-day-world-climate-el-nino-intl/index.html (visited on 07/15/2023).

Parry, Ian W. H., Simon Black, and James Roaf (2021). *Proposal for an international carbon price floor among large emitters*. OCLC: 1298722213. Washington, DC: International Monetary Fund. ISBN: 978-1-5135-8425-6.

Rafaty, Ryan, Geoffroy Dolphin, and Felix Pretis (Oct. 21, 2020). *Carbon Pricing and the Elasticity of CO2 Emissions*. Rochester, NY. URL: https://papers.ssrn.com/abstract=3812786 (visited on 09/04/2023).

Regeringskansliet, Regeringen och (Feb. 26, 2018). *Sweden’s carbon tax*. URL: https://www.government.se/government-policy/swedens-carbon-tax/swedens-carbon-tax/ (visited on 03/19/2023).

Sato, Misato et al. (2022). “Allocation, allocation, allocation! The political economy of the development of the European Union Emissions Trading System”. In: *WIREs Climate Change* 13.5. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/wcc.796, e796. ISSN: 1757-7799. DOI: 10.1002/wcc.796. URL: https://onlinelibrary.wiley.com/doi/abs/10.1002/wcc.796 (visited on 09/02/2023).

STXE 600 PR.EUR (^STOXX) Charts, Data & News - Yahoo Finance (2023). URL: https://finance.yahoo.com/quote/%5ESTOXX/ (visited on 09/04/2023).

The Paris Agreement — UNFCCC (2023). URL: https://unfccc.int/process-and-meetings/the-paris-agreement (visited on 03/07/2023).

UK Emissions Trading Scheme markets (2023). URL: https://www.gov.uk/government/publications/uk-emissions-trading-scheme-markets/uk-emissions-trading-scheme-markets (visited on 03/15/2023).

US EPA, OAR (Mar. 27, 2020). *Acid Rain Program Results*. URL: https://www.epa.gov/acidrain/acid-rain-program-results (visited on 03/06/2023).

What is Carbon Pricing? — Carbon Pricing Dashboard (2023). URL: https://carbonpricingdashboard.worldbank.org/what-carbon-pricing (visited on 03/08/2023).

What is the Kyoto Protocol? — UNFCCC (2023). URL: https://unfccc.int/kyoto_protocol (visited on 03/07/2023).

World Meteorogical Organization (WMO) (2022). *Scientific Assessment of Ozone Deplation: 2022*. GAW 278. Geneva: WMO, p. 56. URL: https://ozone.unep.org/system/files/documents/Scientific-Assessment-of-Ozone-Depletion-2022-Executive-Summary.pdf.

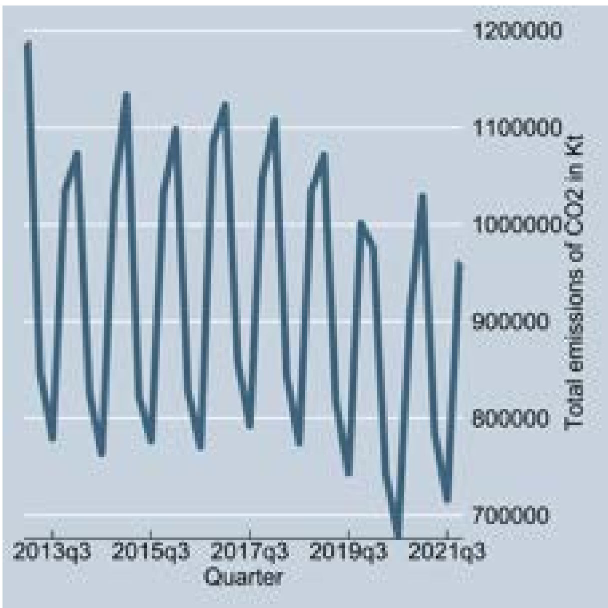
Yao, Riquan et al. (Jan. 2023). “The Impact of China’s ETS on Corporate Green Governance Based on the Perspective of Corporate ESG Performance”. In: *International Journal of Environmental Research and Public Health* 20.3. Number: 3 Publisher: Multidisciplinary Digital Publishing Institute, p. 2292. ISSN: 1660-4601. DOI: 10.3390/ijerph20032292. URL: https://www.mdpi.com/1660-4601/20/3/2292 (visited on 08/17/2023).

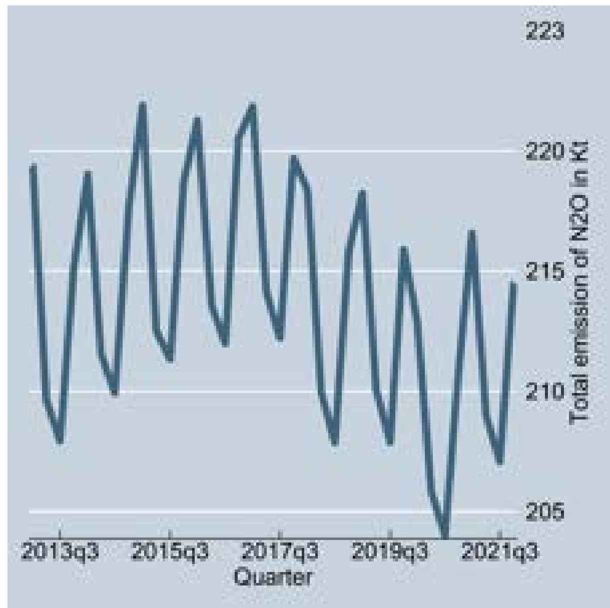
Zhang, Yifei et al. (Aug. 20, 2020). “The effect of emission trading policy on carbon emission reduction: Evidence from an integrated study of pilot regions in China”. In: *Journal of Cleaner Production* 265, p. 121843. ISSN: 0959-6526. DOI: 10.1016/j.jclepro.2020.121843. URL: https://www.sciencedirect.com/science/article/pii/S0959652620318904 (visited on 08/20/2023).

Appendix

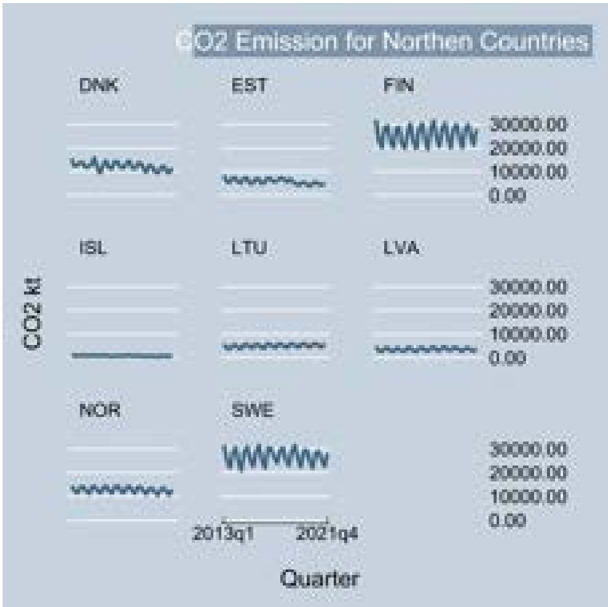
This Appendix provide figures to better understand the changes of the variable used in the analysis.

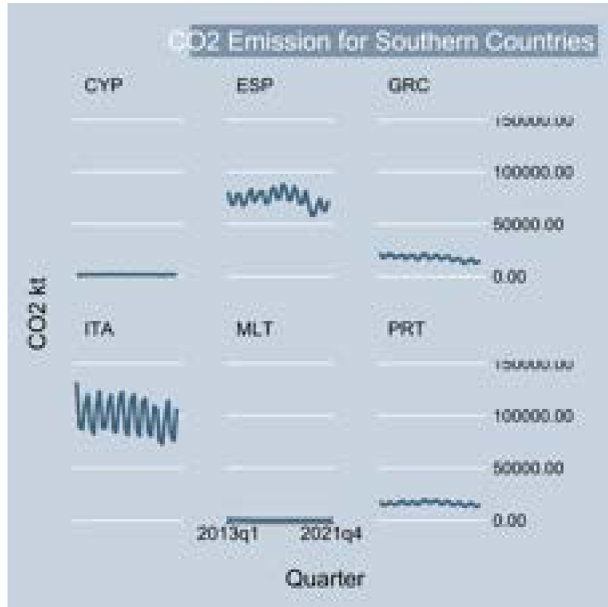
Total Emissions of CO2 and N2O for Europe.

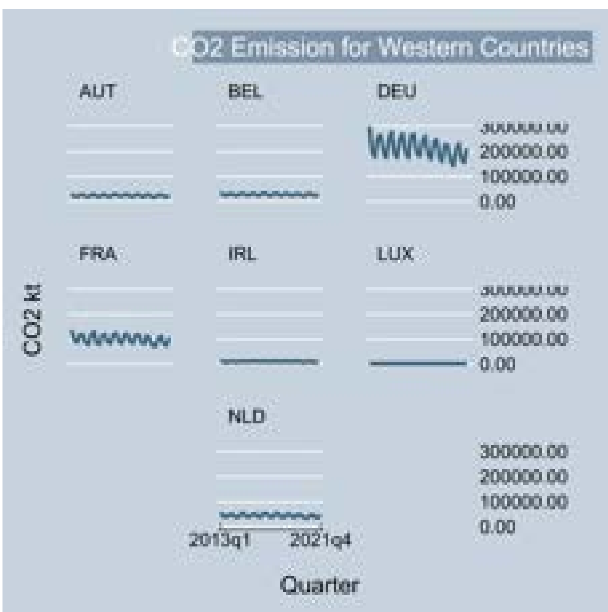


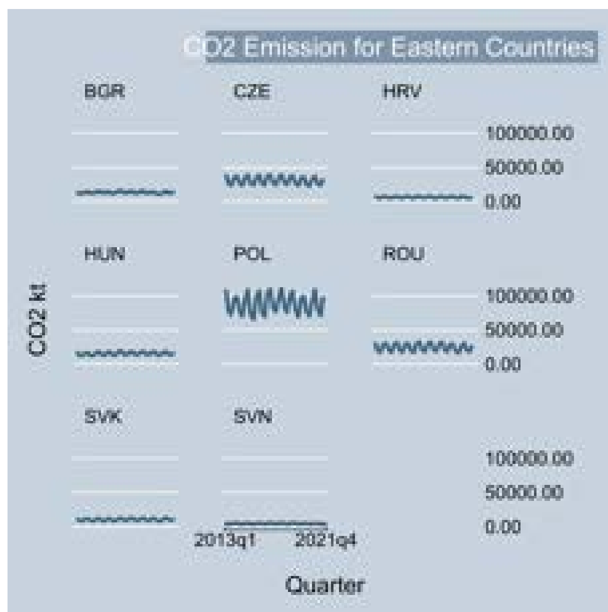


CO2 emissions broken down by country.

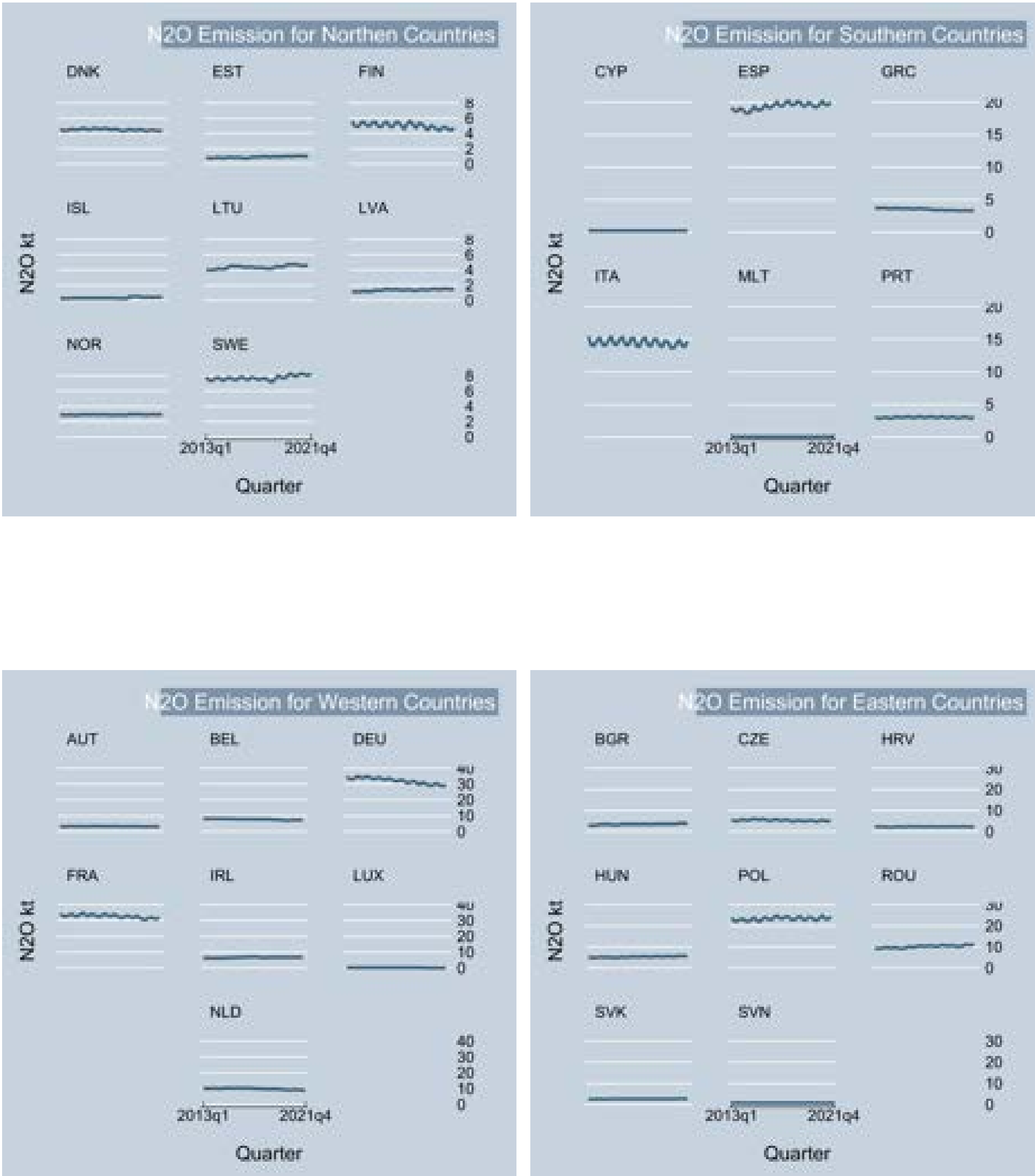




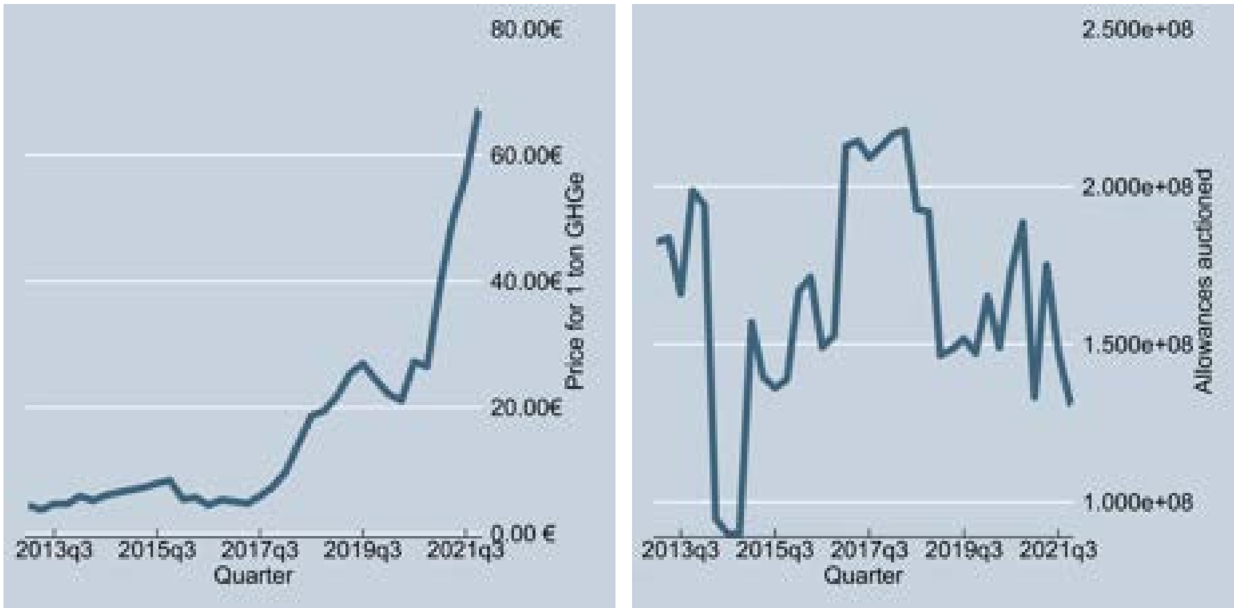




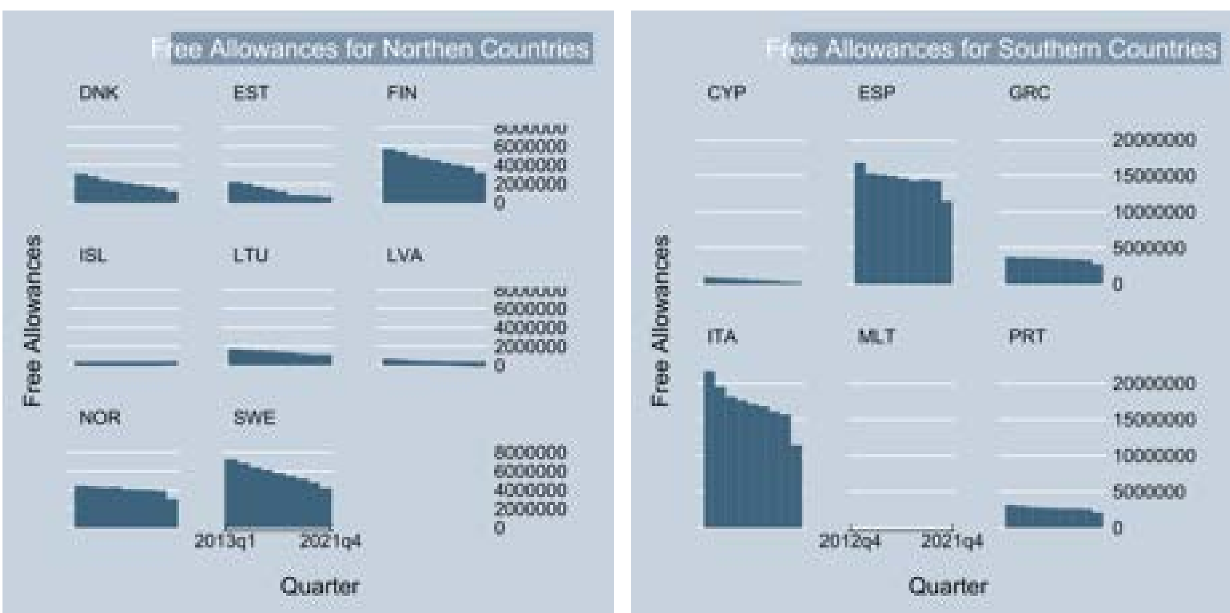
N2O emissions broken down by country.



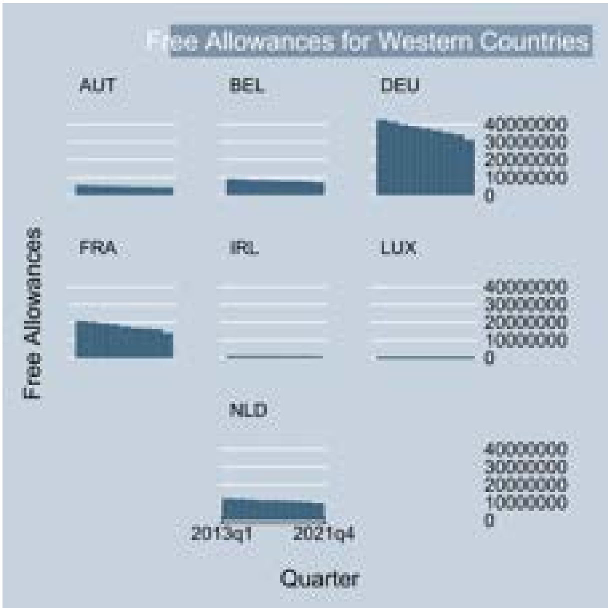
Price and total number of allowances.

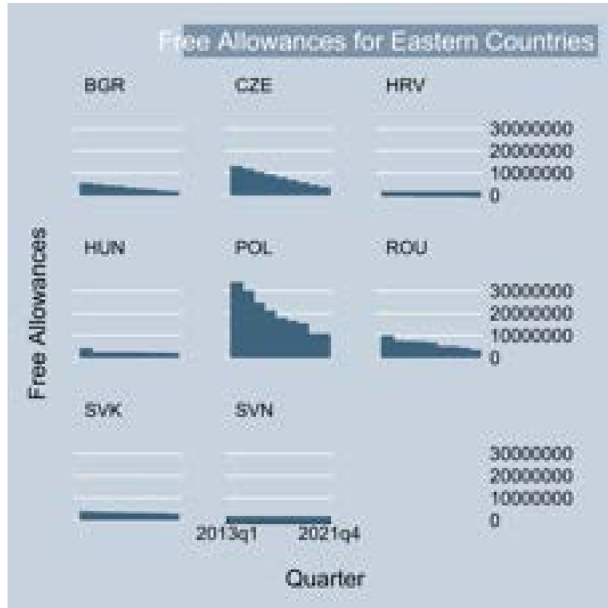


Free allowances broken down by country.

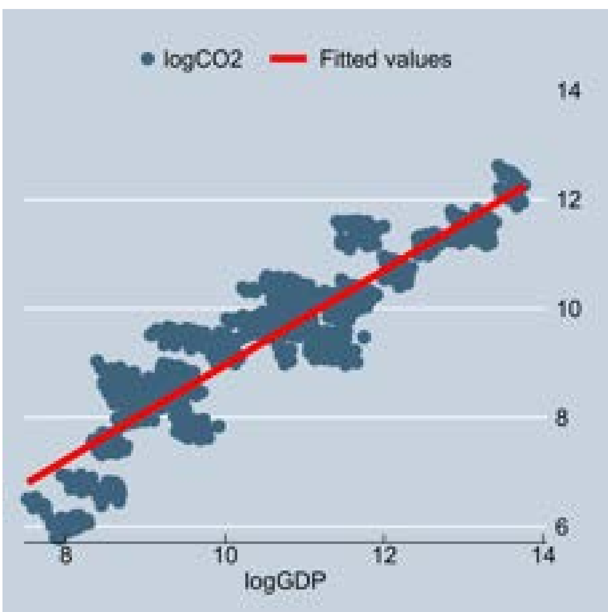


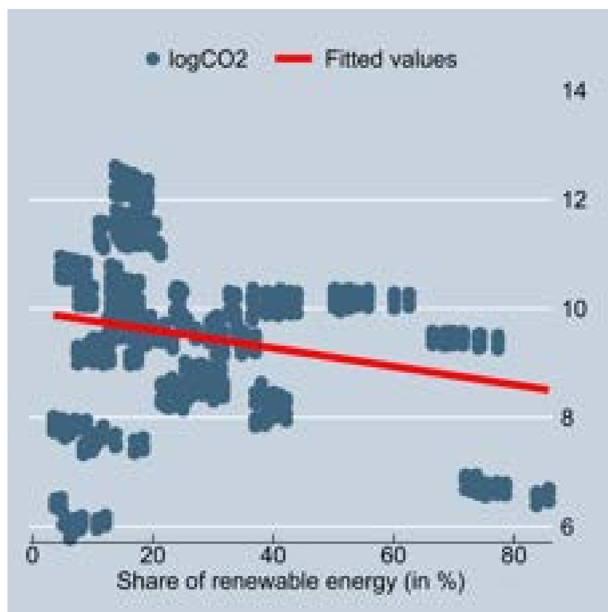
Free allowances broken down by country (continued).





Correlation between CO2 and GDP and between CO2 and share of renewable energy.





CO2 and E score broken down by country.