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"Emissions and Allowances in the EU Emissions Trading System after the Paris Agreement"

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Abstract

In this paper, I examine how allowances allocation affected emissions of power sector installations in the EU ETS following the Paris Agreements. The dataset I use covers the 2010-2022 period, includes the emissions and allowances of 4,498 installations operating in power sector across the 27 Member States of the European Union. I discover that installations receiving lower allowances in the first quartile (Q1) reduced their emissions by 3.5% from 2016 to 2022 compared to the 2010-2015 period. I find no evidence on the installations in second, third and fourth quartiles due to the country specific developments. I also show that country characteristics have a crucial role in policy effectiveness because the emissions of installations located in lower-income Member States entered into the EU at later stages did not fall.

JEL Classification: Q40, Q48, O13, H32, L25.

Keywords: Emissions, Paris Agreement, Power sector, Climate change.

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1 Introduction

Global emissions must urgently start to decline to keep the planet habitable. To mitigate the catastrophic consequences of climate change, a landmark agreement of the Paris Agreement was adopted under the United Nations Framework Convention on Climate Change (UNFCCC) at the Conference of Parties 21 (COP21) in December 2015. With the aim of preventing the global rise of temperatures, 195 countries set the climate goal of holding "the increase in the global average temperature to well below 2°C above pre-industrial levels" and "pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels".[1] As a turning point in the history of tackling climate change, the Paris Agreement triggered global action, numerous policy initiatives and international partnerships around the world. Countries submitted their national plans referred as Nationally Determined Contributions (NDCs) to reach the targets set in the agreement and began to design and implement policies. Governments began to develop strategies in order to decarbonise their economies and intensified their regulatory efforts to curb greenhouse gas (GHG) emissions.

Previous studies documented that implementation of the Paris Agreement can reduce emissions (Wu et al., 2022), lower global demand for fossil fuels (Vrontisi et al., 2020), protect marine life and ecosystem (Sumaila et al., 2019) and generate net economic benefits despite marginal abatement costs differ across regions (Liu et al., 2020). However, more ambitious targets and actions might be needed to keep the global warming below 2°C (Rogelj et al., 2016; Liobikienė and Butkus, 2017; Roelfsema et al., 2020) and inability to achieve the targets might accelerate the sea-level rise rapidly and make it unstoppable (DeConto et al., 2021).

Climate and energy goals have been the core elements of the European Union's policymaking. The European Union (EU) set increasingly ambitious targets for reducing the greenhouse gas (GHG) emissions which it frequently updates in accordance with new scientific evidences and reaching a net-zero continent by 2050. In 2005, the EU Emissions Trading System (EU ETS) was launched as the cornerstone of European climate policy. The EU ETS aims to reduce carbon emissions in a cost-effective manner and generate incentives to firms for development and use of cleaner technologies through market mechanism.[2]

Emissions trading schemes have been increasingly preferred policy choice around the world because of their greater compliance flexibility and cost effectiveness. Among carbon

[1] UNFCCC. United Nations Framework Convention on Climate Change. Report No. FCCC/INFORMAL/84, https://unfccc.int/resource/docs/convkp/conveng.pdf (UNFCCC, 1992).

[2] More recent and a comprehensive climate strategy has been the European Green Deal approved in 2020. With a set of policies covering a wide range of industries, the European Green Deal committed to reduce their CO2 emissions 55% by 2030 and become the first climate neutral continent by 2050.

pricing mechanisms, the ETS and carbon taxes consist of two main policy tools that policymakers rely on. Carbon taxes require polluters to pay for their certain amount of emissions at a price determined by the policymaker. Under the ETS, the central authority allocates tradable emissions allowances to plants or the allowances are auctioned off, and tradable allowances give firms right to emit a certain amount of emissions into the atmosphere. Firms with shortage of allowances can buy allowances from plants with excess of allowances whereas firms with excess of allowances can sell them to the plants needing additional allowances in the market. Emissions trading systems are designed with a purpose of creating incentives for firms to reduce their emissions. To be able to reduce emissions, firms can reduce emissions by either adoption of cleaner technologies or lowering output.

The objective of this study is to investigate the role of allowances in emissions reduction of power plants regulated in the EU ETS after the Paris Agreement by focusing on the period between 2010 and 2022. I discover that installation size measured based on allowances allocation had an important role in the power sector's emissions reduction. I find that reduced allowances induced 3.5% lower emissions for installations located in the first quartile (Q1) of allowances size distribution relative to their peers in the same quartile after the adoption of the Paris Agreement. However, I do not find any evidence of emissions reduction for the installations in lower income Member States entered into the EU during the enlargement periods after 2004. The results indicate that the country characteristics and specific developments over time such as national regulatory changes, supply shocks, macroeconomic conditions play an important role in the effectiveness of the EU ETS policies.

There are several reasons why power sector in the EU is the ideal case study to examine the relationship between emissions and allowances. The sector was subject to more stringent regulation because the authorities considered that it has more options to reduce emissions and less exposed to international competition (carbon leakage). As a result, power sector received fewer allowances compared to other industries and Ellerman and Buchner (2008) showed that it was the only sector received allowances below its verified emissions. Moreover, decarbonization of energy producers through low carbon technology usage plays a key role in mitigating emissions and meeting the commitments of the Paris Agreement (Mathy et al., 2018).

Power sector plays a critical role in achieving net zero targets because global energy demand continues to rise and the biggest increase in carbon emissions has been in power and heat sectors in 2021 (IEA, 2021). Power sector is closely linked to macroeconomic conditions as it tends to pass-through the cost increases to its consumers (firms and households) (Chan et al., 2013; Fabra and Reguant, 2014). Thus, it can create spillover effect on the economy to a wider extent, exacerbating inflation, disrupting production and reducing living standards. Finally, Joltreau and Sommerfeld (2019) highlight that the reason why some studies find no impact on competitiveness might be because of over-allocation of emissions allowances and cost pass-through onto consumers.

A large body of literature investigated the effectiveness of the EU ETS in emissions reduction and discovered that the policies under the EU ETS helped to reduce emissions in the EU (Bayer and Aklin, 2020; Känzig and Konradt, 2023; Böning et al., 2023; Känzig, 2023). The EU ETS has successfully reduced emissions in Phase I (Ellerman and Buchner, 2008; Ellerman et al., 2010; Anderson and Di Maria, 2011) and the first two years of Phase II relative to baseline scenario (Abrell et al., 2011). Country specific studies show that regulated firms under the EU ETS reduced their emissions relative to unregulated firms in France (Wagner et al., 2014; Colmer et al., 2022; Dechezleprêtre et al., 2023), Germany (Petrick and Wagner, 2014), Norway (Klemetsen et al., 2020; Dechezleprêtre et al., 2023), the UK (Ellerman and McGuinness, 2008; Dechezleprêtre et al., 2023) and the Netherlands (Dechezleprêtre et al., 2023). In contrast, Calel (2020) finds no improvement in firms' carbon intensity in the UK and Jaraite-Kažukauske and Di Maria (2016) find slight reduction in emissions intensity but not the absolute emissions of Lithuanian firms.[3]

This paper is related to studies examining the emissions reduction in the EU ETS and its relation with the free allowances based on installation-level data. Previous studies highlighted that the design of allowances allocation rules has important implications in operators' behavior. Dechezleprêtre et al. (2023) study the 2005-2012 period relying on 480 installations (240 pairs from matching) across various sectors from 4 European countries while De Jonghe et al. (2020) study the 2010-2020 period relying on 3,952 firms from 27 European countries and find that less allowances allocated induced larger emissions reduction in the EU ETS. The sample size in my analysis includes 4,498 installations subject to the EU ETS in power sector across 27 Member States and spans longer period from 2010 to 2022. Different than the previous studies examined various sectors in the EU ETS, I focus only on the installations regulated in the power sector which was treated distinctly as it had to auction its allowances from 2013 on. Moreover, the dataset used in this paper distinguishes the fossil fuel types and allows me to control for fuel-specific developments over time.

The study in this paper also contributes to the literature investigating the implications of the Paris Agreement. Salman et al. (2022) and Okorie and Wesseh Jr (2023) find that country-level GHG emissions declined following the Paris Agreement. This paper departs from these studies by providing installation-level evidences from all countries in the power sector regulated under the EU ETS. Fahmy (2022) shows that the preferences of investors have changed after the Paris Agreement which might have had noteworthy implications

[3] See the studies focusing on the impact of EU ETS on firm competitiveness: Chan et al. (2013), Abrell et al. (2011), Anger and Oberndorfer (2008), Jaraite-Kažukauske and Di Maria (2016).

on the activities of power operators as well. Thus, more evidences at the micro-level are needed in order to better understand the behavior of operators. Additionally, Wang et al. (2024) reveal the significant relationship between enterprise size and abatement costs. My analysis focuses on the specific policy tool of allowances allocation in the EU ETS and its effectiveness in reducing power sector emissions while highlighting the importance of operator size.

The rest of the paper is as follows. Section 2 provides institutional details for the institutional restructure of the EU ETS and the dataset. Section 3 introduces empirical analysis and Section 4 concludes.

2 Context and Data

In this section, I briefly explain the institutional structure and trading phases of the EU ETS and introduce the dataset. I further present some descriptive evidences before moving to the main empirical analysis.

2.1 Institutional Structure of the EU ETS

The EU launched the world's first international carbon trading scheme in the world in January 2005, the European Union Emissions Trading System (EU ETS). As one of the largest carbon markets in the world, the EU ETS is a cap-and-trade system accounting for more than 40% of the EU's total emissions.

Under the cap-and-trade systems, a political authority sets a cap for total annual emissions and distributes emissions allowances equivalent to the cap among emitters. An allowance corresponds to each metric ton of carbon emitted and installations surrender their allowances until the compliance date at the end of the year. During the year, installations can purchase extra allowances in the market if their emissions exceed their allowances or, they can sell or save their allowances if they emit less than their allowances.

One of the key elements of the EU ETS is the allocation of emissions allowances provided to installations freely or through auctioning proportional to installation's production capacity. During the Phase 1 and 2, a simple approach referred as grandfathering was preferred in which the free allowances were allocated according to installations' historical emissions. With the introduction of Phase 3 in 2013, fixed benchmarking system was used. Similar to grandfathering, the amount of allowances allocated across installations were determined on the basis of historical emissions but 10% most efficient installations in each sector became the benchmark level.

Allocation of free allowances can be considered as temporary subsidy, offsetting the higher operating costs. Providing free allowances are generally justified on the basis of avoiding carbon leakage (relocation of businesses to unregulated locations) and lobbying for political support.[4] Allowance allocation systems induced considerable over-allocation of free allowances because productivity levels were assumed to be constant over time, i.e. many plants received more allowances than they emitted. Hence, auctioning, which became the allowance allocation rule for the power sector as of 2013, has potential to reduce inefficiencies related to free allowances (Hepburn et al., 2006). Exemptions from auctioning were generally granted to industries with high trade exposure but Martin et al. (2014) find that leakage risk is particularly associated with carbon intensity rather than trade exposure.[5]

The EU ETS has been developed over the years through different trading phases, improvements have been made and emissions cap in each phase has been more stringent. Phase 1 was the three year pilot period from 2005 to 2008 and intended to prepare for Phase 2. The system covered power sector and energy-intensive industries. Companies not compliant with the regulation were required to pay 40 EUR per tonne as penalty. The emissions cap was fixed amount at 2298 Mt CO2e per year. During this period, the EU member states had to provide 95% of emission allowances for free to their installations in the ETS and many firms received more allowances than needed to encompass their emissions. However, emissions data were not reliable and over-allocation of free allowances led carbon price drop to zero.

Phase 2 lasted from 2008 to 2012. During pilot period of Phase 1, the data on verified annual emissions were collected and the cap on allowances was lowered 6.5% compared to 2005. During this period, the threshold for handing out free allowances were reduced to 90% from 95% and the penalty for non-compliance increased to 100 EUR per tonne. During Phase 1 and 2, the European Commission provided general guideline but the national governments in the EU determined the allocation and the distribution of allowances across sectors. Moreover, the EU ETS received criticisms over its inefficiently emissions reduction requirements for installations. In the first years of Phase 2, the Great Financial Crisis in 2008 reduced emissions substantially due to the contraction in the economy and led to large surplus of allowances.

Phase 3 operated from 2013 to 2020, the EU ETS partially shifted from free allocation of allowances to auction. In the power and heat generation sectors, producers did no longer receive free allowances and auctioning has become the "default method" for allowances allocation.[6] For energy-intensive and other manufacturing industries, free allowances remained as the default-allocation method if they were at risk of carbon leakage but experienced gradually phase out of free allowances otherwise. An important reform in this phase has been that EU-wide benchmarks were considered in emission performance

[4]Free allocation tends to generate political influence for over-allocation of emission allowances (Anger et al., 2016).

[5]There are different policy options for free allowances to be allocated such as according to highest propensity of carbon leakage and highest marginal improvements in policy objective.

[6]Some countries are exempted from this regulation and details are provided in the following section.

and thus an EU-wide cap for emissions reduction was used instead of national allocation plans. Phase 2 and 3 allowed firms to utilise unused allowances in subsequent periods which prevented the price to drop below zero despite over-allocation of allowances.

Phase 4 started from 2021 onwards to be operated through 2030 and the EU extended the rules to ensure better functioning of the system. The amount of allowances will decline annually 2.2% compared to the current rate of 1.74% with the aim of reducing an additional amount of 556 million tonnes of emissions during this period. Furthermore, the EU established Market Stability Reserve (MSR) in 2019 to reduce the inefficiencies arising from over-allocation of allowances in the market.

2.2 Data

The datasets I use in the analysis are provided by Ember, a think-tank based in the UK. I use two datasets from Ember's data catalogue. *EU Power Plant Emissions Data* is a micro dataset provided at the plant-level[7] and *Yearly Electricity Data* which is a macro level dataset provided at the country-level.[8] The analysis based on these two datasets span the 2010-2022 period.

EU Power Plant Emissions Data is based on the power sector of the EU ETS which include heat and power plants but the plants of biomass and some waste generation are not available in the data. The installations in the dataset account for 90% of EU-ETS power sector emissions in 2022 and cover power plants from 28 countries which are listed in Table A1 of Appendix A.[9] The plant level emissions are distinguished by fuel categories such as gas, hard coal, lignite, oil and other fossil fuels. The category indicated as other fossil fuels includes peat, non municipal waste, oil and blast furnace gases. Matching of power installations by fuel type relies on ETC/CME Report 10/2021.[10]

Yearly Electricity Data includes yearly electricity generation, capacity, emissions and demand data from over 200 geographies. The information available in this data are collected from different sources.[11] The data include country-level information on various variables but I only use a sample of the EU countries because the plant-level emissions data is only provided for the EU members. Electricity generation (TWh) is distinguished by fuel category and aggregated. Electricity demand (TWh) corresponds to summation of power production and net imports. Installed power generation capacity (GW) are

[7]See the link for the dataset: https://ember-climate.org/data-catalogue/eu-power-plant-emissions-data/

[8]See the link for the dataset: https://ember-climate.org/data-catalogue/yearly-electricity-data/

[9]In the sample, some installations did not report the data on their emissions for 2022. Ember calculated their estimated emissions as a percentage change from 2021 according to the sector the installation belongs to.

[10]See the link to access the details: https://www.eionet.europa.eu/etcs/etc-cme/products/etc-cme-reports/etc-cme-dataset-1-2021-supplemental-information-to-etc-cm-report-10-2021.

[11]See the Appendix C for more details regarding the data providers used for the data collection.

collected from various sources and provided for different fuel types. Emissions from electricity generation (Mt CO2e) is calculated according to IPCC emissions factors from the IPCC 5th Assessment Report Annex 3. These emissions represent full lifecycle emissions including upstream methane, supply-chain and manufacturing emissions, and all gases converted into CO2 equivalent over a 100 year timescale.[12]

2.3 Descriptive Evidences

As mentioned in the previous section, the dataset covers around 90% of power sector emissions in the EU ETS. Table 1 presents the number of observations. Column (1) shows the number of observations across countries from 2010 to 2022. Column (2) displays the number of installation in each country. The distribution of the number of observations and the number of installations largely corresponds to the sizes of countries and their power generation capacities, i.e. reflecting the representatives of the data.

Table 2 displays the statistics for verified emissions and allocated allowances before and after the Paris Agreement for the period between 2010 and 2022. As it can be evidently seen, average emissions are lower after 2015 as well as allocated allowances.

Table 3 shows the total CO2 emissions of each country before and after the Paris Agreement. Most of the countries have lower emissions in the power sector after 2016 except four countries: Croatia, Cyprus, Poland and Slovakia. In the dataset, two fossil fuel installations operating in power sector of Malta are categorized in "Other Fossil Fuels". Both of them do not report verified emissions after 2012.

In Figure 1, I show total verified emissions of installations and total allowances allocated to them from 2010 to 2022 in natural logarithms. While both indicators have been in downward trend over time, there has been a growing gap as allowances were reduced more rapidly than the fall in emissions after 2013. Notice that the sharp decline in allowances in 2013 corresponds to the start of Phase 3.

In Figure 2, I illustrate the verified emissions aggregated across the fuel types between 2013 and 2022. Except that of gas, most emissions from fossil fuels declined after 2015 even though some of them were already in downward trend before. Despite a rebound from a steep fall due to COVID-19 in 2020, emissions started to decline immediately following the treaty. It is consistent with the previous findings that the Paris Agreement had somewhat effect on emissions reduction (Okorie and Wesseh Jr, 2023) but such efforts are yet considered insufficient (Rogelj et al., 2016; Roelfsema et al., 2020).

We must consider the fact that after the Paris Agreement, energy markets experienced shocks that had significant effects. The first shock was the COVID-19 that disrupted the demand through reduced mobility and supply through restricted production for the

[12]See more details regarding the construction of this dataset in the following link: https://ember-climate.org/app/uploads/2022/07/Ember-Electricity-Data-Methodology.pdf

energy. The impacts of the COVID-19 pandemic lasted from 2020 up to almost 2022. The second shock was the Russo-Ukrainian War emerged in February 2022 that led to spike in energy prices and forced the global economy shift away from imports of fossil fuels from Russia, particularly gas.[13]

With the start of Phase III in 2013, power sector was required to buy all of its allowances from auctioning under the EU's Emissions Trading System (EU ETS). A provision in the EU ETS Directive referred as Article 10c allowed ten Member States hand out free allowances to their power sectors. Derogation in Phase 3 was intended to facilitate energy transition through energy diversification though this exemption to lower-income countries did not reduce fossil fuel dependence in Poland (Müller and Teixidó, 2021). During the Phase 3 (2013-2020), only Latvia and Malta chose not to use this derogation while other eight eligible Member States (Bulgaria, Cyprus, Czechia, Estonia, Hungary, Lithuania, Poland and Romania) have made use of the derogation under Article 10c of the ETS Directive.

Figure B1 in Appendix B illustrates the total emissions and allowances of the installations while excluding the Member States made use of the derogation under Article 10c of the ETS Directive. Thus, only the installations receiving allowances through auctioning instead of free allocation are presented in this graph. The pattern appears to be substantially similar to Figure 1 in which the emissions have been falling slightly over time.

3 Empirical Analysis

In this section, I conduct a more detailed empirical analysis and present the results.

3.1 Emissions Before and After the Paris Agreement

I initially examine the within-installation changes in emissions before and after the Paris Agreement using the following equation:

$$\ln{(E_{ict})} = \alpha_i + \beta * Post + \nu \ln{(X_{ct})} + \varepsilon_{ict} \tag{1}$$

where E_{ict} denotes the emissions of installation i located in country c in year t. α_i is installation-level fixed effects that would control for time-invariant unobserved characteristics of the installations. ε_{ict} is the error term. *Post* is a dummy that takes the value of 1 for the 2016-2022 period and zero for the 2010-2015 period.

Notice that country-level shocks affecting energy demand might also lead to an increase in energy supply and therefore the emissions independently of the Paris Agreement, particularly in absence of technological changes in energy production or improvements in

[13] https://www.iea.org/articles/frequently-asked-questions-on-energy-security

energy efficiency. Hence, I include country-level electricity demand per capita, X_{ct}, as a covariate in the regressions.

The results from estimating Equation (1) is presented in Table 4. Country-level institutional settings, geography, renewable energy potential and social characteristics might affect the power sector emissions. Hence, in Column (1), I control for time invariant country characteristics using country fixed effects. In this specification, I find that installation-level emissions declined 11% on average after 2015. In Column (2), I include country-level electricity demand per capita as a covariate and find that the emissions statistically significantly declined around 8%.

Column (3) shows the results when I incorporate fuel-type fixed effects to isolate the heterogeneity in energy resources such as propensity of natural resources extraction or market characteristics of each fossil fuel type at the international level. Finally, Column (4) includes both installation-level fixed effects and electricity demand per capita. Installation-level fixed effects control for time-invariant unobservable factors that might affect the pollution of each plant.[14] In this case, the coefficient of interest increases to -0.382 and remains statistically significant at the 1% level.

In all specifications, I find that the installation-level emissions declined following the Paris Agreement and the results are statistically significantly at the 1% level. The estimation results suggest that the within-installation emissions declined 46% on average during the 2016-2022 period compared to the 2010-2015 period.[15] This finding is substantially larger than less cautious specifications provided in Column 1-3, i.e. highlighting the role of individual installation characteristics.

The drawback of these regression results from estimating Equation 1 is that it considers the same sample group before and after 2015. Installation-level emissions might have already been in downward trend before 2015 and in that case, I will confound the time trend. Therefore, based on these findings, I cannot infer what would have happened to the emissions if the Paris Agreement was not adopted. In order to understand the policy effectiveness, I continue the analysis by assessing the role of allowances allocation in emissions reduction.

3.2 Emissions and Allowances Allocation

As explained in the previous sections, the cap of the EU ETS is set by the EU and allowances allocated based on the cap are distributed among installations proportional to their historical emissions. Hence, we would expect the emissions to decline each year in proportion to allowances received because lower amount of allowances were allocated as the cap on emissions is tightened every year, forcing installations to emit less. I therefore

[14] Notice that I do not control for year specific shocks using time dummies because they would be perfectly collinear with the post-Paris Agreement dummy and omitted from the regressions.

[15] Using the coefficient on *Post* in Column (4), exp (0.382)-1=46%.

examine whether more stringent regulation (less allowances allocated) was associated with larger emission reduction at the installation-level during the whole sample period from 2010 to 2022 and estimate the following equation:

$$\ln(E_{ict}) = \alpha_i + \beta \ln(A)_{ict} + \nu \ln(X_{ct}) + \varepsilon_{ict} \tag{2}$$

where A_{ict} denotes the allowances of installation i in country c in year t. Estimation results of Equation (2) are presented in Table 5.

Each specification controls for unobserved time-invariant installation characteristics. The point estimate slightly rises from 0.0795 (Column 1) to 0.0816 (Column 2) when I control for country-level electricity demand per capita. Including year specific shocks that are common to all installations and fuel-year fixed effects slightly reduces the point estimate to 0.0480 in Column (3) and to 0.0519 in Column (4), respectively. This very small change on the coefficient β when I control for fuel-year fixed effects instead of year fixed effects induces that there is almost no confounding effect particular to fossil-fuel type that might affect the relationship between the emissions and allowances.

Column 5 and 6 additionally control for country-level trends using the country-year fixed effects. The point estimate becomes 0.0854 in both specifications and remains statistically significant at the 1% level. Hence, the regression results suggest that 1% fall in allowances allocated to installations is associated with 0.08% emissions reduction between 2010 and 2022.

Notice that allowances are allocated based on the installations' past emissions performance, we can treat the allowances as exogenous at least partially since a single installation is unlikely able to determine the allowances allocation at the EU level. However, above estimation is still subject to omitted variable bias problem because the efficiency performance of installations may affect their emissions, even if not the allowances they receive in the short term given that allowances are allocated based on the past emissions performance. I do not have any other performance measures of installations in my dataset but I estimate the model by additionally controlling for lagged emissions to overcome these challenges. As the estimation results presented in Table A2 of Appendix A, the coefficients are smaller but remains positive and statistically significant at the 1% level.

Table A3 of Appendix A presents the results for the periods before and after the Paris Agreement separately. The point estimates are positive and statistically significant at the 1% level in all specifications before and after 2015. However, the coefficient on the allowances are smaller in magnitude for the period after the agreement which contradicts the policy expectations of the EU ETS.

3.3 Allowances Allocation After the Paris Agreement

Consider that various developments at installation level, country-level and international level might have driven the findings in previous estimations. More stringent regulation in the EU ETS, energy and climate policies of countries or shocks to energy markets might have contributed to further decline of installation-level emissions after the Paris Agreement. To explore which factors were related to lower emissions, I analyse how installations receiving larger amount of allowances performed compared to those installations receiving lower amount of allowances in the following equation:

$$\ln\left(E_{ifct}\right) = \alpha_i + \beta_1 * \ln\left(A\right)_{ifct} + \beta_2 * Post * \ln\left(A\right)_{ifct} + \nu \ln\left(X_{ct}\right) + \eta_{ft} + \lambda_{ct} + \varepsilon_{ifct}. \tag{3}$$

The coefficient of interest is β_2, capturing the average change in the emissions of installations received larger allowances compared to installations with lower allowances after 2015. I could include *Post* dummy as an additional explanatory variable but it is subsumed in this setting because I include more disaggregated fuel-year and country-year fixed effects.

Various factors such as fossil fuel prices, economic growth, weather, marginal abatement costs and uncertainty tend to affect the carbon price in the EU ETS (Hintermann et al., 2016). I include year fixed effects to control for carbon price which is time varying parameter common to all installations regulated under the EU ETS.[16] I also incorporate fuel-year fixed effects to control for regulatory or policy changes targeting different fuel types and affecting fuel prices heterogeneously. Notice that fuel-year fixed effects can also control for fuel specific technological changes as well as general equilibrium effects of carbon price on different fuel costs.

Installations may face different demand for energy depending on their location and macroeconomic conditions such as economic growth, uncertainty and weather conditions in different countries. To take into account such threats to identification, I include installation fixed effects and country-year fixed effects in the estimations.

Moreover, specific policies of the Member States might have targeted installations with high or low allowances differently, even prior to the Paris Agreement. Such policies might have compensated their losses and therefore generating incentives for higher emissions by increasing output. This point refers to parallel trends assumption in difference-in-differences estimations. This is critical issue for the identification as it would indicate smaller and larger installations (those with less and more allowances) would have same emissions reduction trends had the public policies following the Paris Agreements not been introduced. To have a valid estimate, conditional on the model's covariates, the potential outcomes of installations receiving more allowances would have followed parallel trends

[16] I acknowledge that an ideal control of carbon price would be daily rather than annually but this would be unsuitable because the unit of observation varies on a yearly basis.

with installations receiving less allowances in absence of the Paris Agreement. However, I am not aware of such political interventions that might have affected installations with various allowance levels differently.

I assume that potential emission change at one installation is independent of allowances allocated to other installations, i.e. there are no spillover and general equilibrium effects between installations. This assumption might be violated if a power installation is providing the significant proportion of a country's energy or if the local competition is low among power stations. However, I do not observe concentration of emissions in a single installation in any country.

Additionally, more stringent allowances allocation might reduce emissions of a power station substantially and the local competitor might increase its emissions by fulfilling the energy demand. In contrast, I cannot think of any unreasonably heterogeneous allowances allocation to a particular installation that might have some consequences to its competitor because the metric used for allowances allocation is implemented to every installation equally.

Table 6 presents the results of estimating Equation (3). Column 1 and Column 2 show that the signs of interaction term are positive and statistically significant at the 1% level when I include *Post* dummy variable instead of fuel-year and country-year fixed effects. The results reveal that installations with lower allowances reduced their emissions compared to installations with higher allowances after 2015 where the point estimate is -0.00981.

As I include year and fuel-year fixed effects in Column 3 and Column 4, the signs of the coefficients of interest remain statistically significantly positive. In contrast, Column 5 shows that the coefficient of interest turns to negative when I control for country specific developments using country-year fixed effects. This finding indicates that omitting country-level time variant factors leads to upward bias in the estimations as they affected allowances and emissions in the same direction. Thus, installations located in certain countries had lower emissions as they received lower allowances but not conditioning on country-level developments in the regressions prevents from identifying the true effect. I argue that this finding highlights the critical role of country specific changes over time in reducing emissions. Finally, the coefficient on the interaction term becomes statistically insignificant when I additionally include fuel-year fixed effects as shown in Column 6.

Negative relationship between allowances and emissions is somewhat intriguing because the purpose of policymakers in the design of the EU ETS is to reduce the emissions of installations by allocating less allowances each year. I argue that particularly two reasons can explain this finding. First, carbon price in the EU ETS has been very low and fluctuating substantially during some periods due to several reasons. Lower carbon price would make the emissions exceeding allowances less costly for installations and power generators might have then emit more without much concern.

Second, a noteworthy problem with free allocations is that firms might have an incentive to emit more today to obtain more free allocation in the future. The findings of Branger et al. (2015) support this argument as they show that firms strategically adjusted their output levels to receive larger amount of free allowances.[17] However, considering the fact that power sector did no longer receive free allowances in the EU ETS after 2013, the latter explanation would be rather irrelevant.

3.4 The Role of Installation Size

There is obviously a systematic difference between the installations with lower and higher emissions, i.e. receiving smaller and larger amounts of allowances. Economic literature documents that firms with larger and smaller size tend to behave differently such as involving in cross-border activities and adopting new technologies (e.g. Bustos, 2011). Assuming that an installation's size in output is proportional to its emissions, larger operators might more easily involve in strategic behaviors such as increasing output capacity or adopting cleaner technologies.[18] To see whether installation size matters in emissions reduction, I estimate the following equation:

$$E_{ifct} = \alpha_i + \sum_{r=1}^{4} \delta^r \left(Q^r_{ict} * \ln{(A)}^r_{ict} \right) + \sum_{r=1}^{4} \varphi^r \left(Q^r_{ict} * Post * \ln{(A)}^r_{ict} \right) + \eta_{ft} + \lambda_{ct} + \varepsilon_{ifct} \quad (4)$$

where r indexes the four quartiles of the allowances size distribution and Q^r_{pct} are dummy variables taking the value of 1 when installation i belongs to quartile r. I take the year of 2016, the first year following the Paris Agreement, as a base period to identify allowances size distribution.

Estimation results are presented in Table 7. Column 1 shows the results from estimating Equation (4) where the coefficients of interest, φ^r, are positive and statistically significant for all quartiles. Column 2 presents the findings that incorporate per capita electricity demand as control. The coefficient estimates remain positive and statistically significant while their magnitudes change only slightly.

Controlling for year (Column 3) and fuel-year fixed effects (Column 4) do not affect the precision of the estimations but only the point estimates to some extend. Finally, Column 5 and Column 6 report results when I control for country-year fixed effects and additionally fuel-year fixed effects, respectively. The point estimates for the installations

[17]Similarly, Bustamante and Zucchi (2022) also find strategic behavior among firms having low balance of carbon credits which adopt precautionary policies to minimize their need to buy carbon credits. In these cases, firms cut production to reduce consumption of credits and invest in green. Conversely, large balance of carbon credits reduces precautionary need of firms: they increase production, reduce engagement in green, leading to higher emissions.

[18]The optimal choice for an installation would depend on various parameters such as abatement costs, carbon price and future energy markets.

in the second, third and fourth quartiles become statistically insignificant. In contrast, the coefficient on the first quartile installations is 0.0521 and statistically significant at the 1% level. The estimations reveal that 1% reduction in allowances induced 0.05% lower emissions for small installations in the first quartile compared to their peers in the same quartile.

Figure 3 illustrates the results for estimating φ^r in Equation (4). The coefficient estimates are represented in dots and their 95% confidence intervals are plotted as vertical lines along the X-axis. It can be evidently seen that the point estimates are around 0 for second, third and fourth quartile groups. However, the installations in the first quartile size group has diverged from the other quartiles.

The installations in the first quartile (Q1) had 336,711 allowances before the Paris Agreement (2010-2015) and 111,571 (2016-2022) thereafter. Based on this 67% reduction and the coefficient estimate (0.0521), I argue that the emissions declined 3.5% on average in response to allowances allocation following the Treaty.

3.5 Heterogeneous Responses to Allowances Allocation

The European Union experienced 7 enlargement episodes since its establishment in 1957. 5th enlargement has taken place in 2004 and it was the most extensive one which included ten Central European countries. Until today, 5th enlargement is followed by 6th enlargement in 2007 and 7th enlargement in 2013. I distinguish the sample into two groups to assess whether responses to allowances allocation were different for countries those entered into the European Union during the 5th, 6th and 7th enlargement episodes than for those have been the Member State before.

The sample in the first group consists of the countries initially the Member States before significant enlargement: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain and Sweden. I must emphasize that these countries were not exempted from Article 10c and they had to auction their allowances after 2013. The results from estimating Equation (4) for this group of countries are presented in Table 7. The findings are very similar to those in Table 8. Analogous to pooled sample, only smallest installations have reduced its emissions in response to lower allowances after the Paris Agreement while the coefficients on installations in the second, third and fourth quartile are statistically insignificant.

The sample in the group of countries entered into the EU with enlargement policies since 2004 consists of Cyprus, Czechia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, Bulgaria, Romania and Croatia. Notice that these are also the Member States continued to receive free allowances after 2013 due to a provisional exemption referred as Article 10c of the EU ETS Directive. I additionally estimate Equation (4) for this group of countries. As shown in Table 9, in addition to second, third and fourth quartile installations, I lose the significance of the coefficient on the smallest installations located in first quartile as well. This finding indicates that small-size installations in the Member States entered into the European Union lately and also continued to receive free allowances after 2013 did not reduce their emissions in response to lower allowances following the Paris Agreement.

3.6 Discussion

The estimation results indicate that the installation size is an important determinant in assessing the role of allowances allocation on emissions reduction for the installations regulated in the EU ETS after the Paris Agreement. Perhaps most interestingly, omitting country-year fixed effects that controls for country specific changes over time in Member States induces bias in the estimations. This finding suggests that due to some country-level developments, installations receiving fewer allowances in first, second and third quartiles did not reduce their emissions after the adoption of the Paris Agreement. In contrast, I do not find any evidence of such an inertia among smallest operators as those with lower allowances had lower emissions between 2016 and 2022.

I also document heterogeneous responses to emissions reduction among the EU Member States. More specifically, the smallest installations (first quartile group) operating in Member States entered into the European Union through later enlargement periods did not reduce their emissions. One explanation for this finding might be that those installations continued to receive free allowances according to the EU ETS Directive referred as Article 10c but the installations in other Member States had to auction their allowances as from 2013. The other explanation might be the resistance of lower-income Member States towards carbon pricing policy through the EU ETS because transition to cleaner energy tends to be economically more difficult for them due to limited fiscal capacity.

Apart from emissions and allowances, the dataset used in this paper does not provide other time variant installation-level information such as emissions intensity, output level, technology used and employment. Notice that various mechanisms such as carbon leakage, improvements in emissions abatement through technical change or reduced production capacity in response to higher carbon price might affected installations' emission levels. Unfortunately, I am not able to control for these factors and I acknowledge that this is the main limitation of the study.

In the analysis, I assume that allowances and emissions sizes are directly proportional to the output levels of installations. However, a technologically advanced and more efficiently operating installation might report lower emissions and even receiving low allowances despite having high production capacity. However, lack of additional information on installation performance, particularly the output level, does not allow me to check the validity of this assumption.

4 Conclusion and Policy Implications

Devastating impacts of climate change demonstrate that policymakers will urgently need to design more effective policies and implement more stringent regulations to limit greenhouse gas emissions. The 2024 assessment report of climate science advisers in the European Scientific Advisory Board on Climate Change titled *"Towards EU climate neutrality: Progress, policy gaps and opportunities"* calls the EU to revise its policies and phase out of fossil fuel use by 2040.[19] As the most polluting sector, power sector has a critical role in reducing emissions and phasing-out of fossil fuels as soon as possible has become one of the most controversial and hotly-debated topics. Decarbonizing the economies will increase countries' energy demand and therefore energy production from renewable resources is essential strategy for policymakers to tackle the global warming.

This paper uses a dataset on installation-level emissions and allowances across 27 EU Member States to examine the role of allowances allocation on power sector's emissions reduction regulated in the EU ETS following the Paris Agreement. Focusing on the period from 2010 to 2022, I find that installations receiving lower allowances in the first quartile (Q1) reduced their emissions by 3.5% during the post-Paris Agreement period but limiting the allowances had no effect on emissions of second, third and fourth quartile installations. These findings are valid for the installations located in higher-income Member States but not for the installations in lower-income countries entered into the EU during the later enlargement periods.

I cannot rule out that installation-specific productivity shocks might confound the findings because I do not have information on output level, emissions intensity, employment and technology used in plants. Thus, my empirical strategy cannot necessarily identify the causal effect of allowances allocation on emissions. However, my findings suggest that installations size and country-level developments are important determinants in assessing the policy efficiency of the EU ETS.

The findings in this paper reveal that there is still room to implement more stringent allowances allocation policy because lower allowances did not reduce the emissions in the power sector substantially after the adoption of the Paris Agreement. Although limiting the allowances in the EU ETS might raise concerns over carbon leakage, the literature typically documents no evidence of carbon leakage (e.g. Branger and Quirion, 2014; Grubb et al., 2022; Colmer et al., 2022; Dechezleprêtre et al., 2022). Hence, I argue that the EU might further tighten its policy measures in the ETS to align with the its climate objectives.

I focus on the concern about whether allowances allocation successfully lead to fall

[19] See the report from the following link: https://climate-advisory-board.europa.eu/reports-and-publications/towards-eu-climate-neutrality-progress-policy-gaps-and-opportunities/esabcc_report_towards-eu-climate-neutrality.pdf/@@download/file

in emissions and whether the Paris Agreement, a landmark treaty on climate change, contributed to emissions reduction of power sector in the EU ETS. Aligned with the evidences in this paper, De Jonghe et al. (2020) find the sectors receiving less free allowances experienced larger efficiency improvements in emissions reduction. However, the initial distribution of allowances can affect behavior of installation operators and the design of allowances allocation can even create incentives to increase production (e.g. Böhringer and Lange, 2005; Dechezleprêtre et al., 2023). The findings in this study suggest that the emissions declined following the Paris Agreement but the policy efficiency has been only relevant for smaller operators and the initial distribution of allowances allocation has been effective in reducing emissions after the Paris Agreement conditional on the installation-size and location. The effects I found are non-negligible and therefore highlight the need for more research on the performance of installations after the Treaty.

An important contribution for future research might be to consider production level and efficiency of installations by using a more detailed dataset. Additionally, examining the removal of free allocations and transition to auctioning system in power sector would be an interesting avenue to understand how the design of allowances allocation would affect emissions, competitiveness and carbon leakage.

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Tables

Table 1: Number of Observations across Countries

	Total observations (1)	Number of installations (2)
Austria	641	61
Belgium	200	49
Bulgaria	400	37
Croatia	74	8
Cyprus	33	3
Czechia	1563	164
Denmark	2705	259
Estonia	421	39
Finland	4188	472
France	3335	356
Germany	8273	827
Greece	192	42
Hungary	929	91
Ireland	94	24
Italy	3254	371
Latvia	492	44
Lithuania	632	64
Luxembourg	45	5
Malta	6	2
Netherlands	707	85
Norway	197	25
Poland	4760	460
Portugal	300	60
Romania	617	71
Slovakia	680	95
Slovenia	162	22
Spain	1119	228
Sweden	4680	534
Total	40699	4498

Notes: This table presents the number of observations for each country. Column (1) shows total number of observations across countries and Column (2) shows the number of installations in each country.

Table 2: Summary Statistics: Emissions and Allowances

	Before Paris			After Paris		
	Mean	SD	Obs.	Mean	SD	Obs.
Verified emissions	9.049	3.034	21773	8.880	3.044	18926
Allocated allowances	9.007	4.055	21773	7.743	3.677	18926

Notes: This table presents the mean, standard deviation and number of observations for verified emissions and allocated allowances of installations. The statistics are separately sprovided for before and after the Paris Agreement.

Table 3: Total Emissions by Country

	Before Paris Agreement	After Paris Agreement
	(1)	(2)
Austria	17.507	17.390
Belgium	17.395	15.464
Bulgaria	18.990	18.496
Croatia	14.956	16.135
Cyprus	16.808	16.602
Czechia	19.502	19.456
Denmark	18.219	17.590
Estonia	18.159	17.869
Finland	18.471	18.091
France	18.673	17.637
Germany	21.331	21.170
Greece	19.291	18.444
Hungary	18.100	17.910
Ireland	17.429	13.536
Italy	20.148	19.816
Latvia	16.074	15.989
Lithuania	16.381	15.496
Luxembourg	14.975	13.220
Malta	15.584	
Netherlands	18.998	18.221
Norway	15.171	13.021
Poland	20.672	20.688
Portugal	17.666	14.943
Romania	18.964	18.516
Slovakia	17.392	17.597
Slovenia	17.299	17.228
Spain	19.262	16.937
Sweden	17.094	17.026

Notes: This table shows the log of total emissions in energy sector for each country. Column (1) and (2) respectively display the aggregate emissions before and after the Paris Agreement.

Table 4: Plant-Level Emissions After the Paris Agreement

	(1)	(2)	(3)	(4)
Post 2015	-0.107***	-0.0789***	-0.101***	-0.382***
	(0.0252)	(0.0249)	(0.0232)	(0.0181)
Electricity Demand		2.440***	1.917***	2.699***
		(0.341)	(0.326)	(0.277)
Observations	40699	40699	40699	40550
Country FEs	Yes	Yes	Yes	No
Fuel FEs	No	No	Yes	No
Plant FEs	No	No	No	Yes
R-squared	0.313	0.314	0.489	0.909

Notes: The table presents the changes in emissions after the Paris Agreement. Dependent variable is the natural logarithm of emissions. Post 2015 is a dummy variable taking the value of 1 for the 2016-2022 period, and zero for the period 2010-2015. Electricity demand denotes the country-level electricity demand per capita. Standard errors are clustered at the installation-level and shown in the parentheses. ***, ** and * Significant at 1, 5 and 10 percent level, respectively.

Table 5: Relationship between the Emissions and Allowances

	(1)	(2)	(3)	(4)	(5)	(6)
ln(Allowances)	0.0795***	0.0816***	0.0480***	0.0519***	0.0857***	0.0854***
	(0.00600)	(0.00584)	(0.00595)	(0.00597)	(0.00614)	(0.00613)
Electricity Demand		3.371***	0.711**	0.901***		
		(0.297)	(0.290)	(0.310)		
Observations	40550	40550	40550	40550	40550	40550
Plant FEs	Yes	Yes	Yes	Yes	Yes	Yes
Year FEs	No	No	Yes	No	No	No
Fuel-year FEs	No	No	No	Yes	No	Yes
Country-year FEs	No	No	No	No	Yes	Yes
R-squared	0.908	0.909	0.915	0.917	0.921	0.922

Notes: The table shows the regression results from the relationship between the allowances and emissions for the whole sample period of 2010-2022. Dependent variable is the natural logarithm of emissions. ln(Allowances) denotes the natural logarithm of the allowances allocated to the installations. Electricity demand denotes the country-level electricity demand per capita. The list of fixed effects are presented at the bottom. Standard errors are clustered at the installation-level and shown in the parentheses. ***, ** and * Significant at 1, 5 and 10 percent level, respectively.

Table 6: Emissions and Allowances After the Paris Agreement

	(1)	(2)	(3)	(4)	(5)	(6)
ln(Allowances) * Post 2015	0.0202***	0.00981**	0.0256***	0.0254***	-0.0109**	-0.00803
	(0.00517)	(0.00499)	(0.00507)	(0.00542)	(0.00512)	(0.00536)
ln(Allowances)	0.0533***	0.0604***	0.0377***	0.0402***	0.0912***	0.0896***
	(0.00617)	(0.00597)	(0.00604)	(0.00607)	(0.00639)	(0.00631)
Post 2015	-0.489***	-0.374***				
	(0.0526)	(0.0504)				
Electricity Demand		2.879***				
		(0.273)				
Observations	40550	40550	40550	40550	40550	40550
Plant FEs	Yes	Yes	Yes	Yes	Yes	Yes
Year FEs	No	No	Yes	No	No	No
Fuel-Year FEs	No	No	No	Yes	No	Yes
Country-Year FEs	No	No	No	No	Yes	Yes
R-squared	0.910	0.911	0.915	0.917	0.921	0.922

Notes: The table shows the regression results from estimating the relationship between the allowances and emissions following the Paris Agreement. Dependent variable is the natural logarithm of emissions. ln(Allowances) denotes the natural logarithm of the allowances allocated to the installations. Post 2015 is a dummy variable taking the value of 1 for the 2016-2022 period, and zero for the period 2010-2015. Electricity demand denotes the country-level electricity demand per capita. The list of fixed effects are presented at the bottom. Standard errors are clustered at the installation-level and shown in the parentheses. ***, ** and * Significant at 1, 5 and 10 percent level, respectively.

Table 7: Estimations by Quartile of the Allowances Size Distribution

	(1)	(2)	(3)	(4)	(5)	(6)
Post 2015						
× Allowances (Q_1)	0.0799***	0.0784***	0.0822***	0.0784***	0.0545***	0.0521***
	(0.0186)	(0.0185)	(0.0185)	(0.0185)	(0.0189)	(0.0188)
× Allowances (Q_2)	0.0282***	0.0253**	0.0333***	0.0294***	0.00186	0.00143
	(0.00987)	(0.00983)	(0.00971)	(0.00971)	(0.00909)	(0.00903)
× Allowances (Q_3)	0.0245***	0.0172**	0.0283***	0.0254***	-0.00644	-0.00627
	(0.00690)	(0.00670)	(0.00670)	(0.00670)	(0.00648)	(0.00646)
× Allowances (Q_4)	0.0304***	0.0201***	0.0331***	0.0328***	-0.00193	0.000474
	(0.00568)	(0.00548)	(0.00546)	(0.00580)	(0.00545)	(0.00572)
Allowances (Q_1)	-0.0469***	-0.0371**	-0.0352**	-0.0350**	0.0229	0.0206
	(0.0159)	(0.0156)	(0.0152)	(0.0152)	(0.0167)	(0.0168)
Allowances (Q_2)	0.0223*	0.0291**	0.0207*	0.0217**	0.0643***	0.0624***
	(0.0119)	(0.0115)	(0.0111)	(0.0111)	(0.0111)	(0.0111)
Allowances (Q_3)	0.0344***	0.0435***	0.0248**	0.0276**	0.0789***	0.0787***
	(0.0128)	(0.0124)	(0.0122)	(0.0122)	(0.0118)	(0.0118)
Allowances (Q_4)	0.0770***	0.0803***	0.0524***	0.0573***	0.102***	0.103***
	(0.00879)	(0.00872)	(0.00904)	(0.00911)	(0.00904)	(0.00906)
Post 2015	-0.562***	-0.466***				
	(0.0596)	(0.0569)				
Electricity Demand		2.812***				
		(0.272)				
Observations	40550	40550	40550	40550	40550	40550
Plant FEs	Yes	Yes	Yes	Yes	Yes	Yes
Year FEs	No	No	Yes	No	No	No
Country-Year FEs	No	No	No	No	Yes	Yes
Fuel-Year FEs	No	No	No	Yes	No	Yes
R-squared	0.911	0.912	0.916	0.917	0.922	0.923

Notes: The table shows the regression results from estimating the relationship between the allowances and emissions following the Paris Agreement for various quartiles of allowances size. Dependent variable is the natural logarithm of emissions. Allowances (Q) with numeric subscripts denote the natural logarithm of the allowances allocated to the installations in each quartile. Post 2015 is a dummy variable taking the value of 1 for the 2016-2022 period, and zero for the period 2010-2015. Electricity demand denotes the country-level electricity demand per capita. The list of fixed effects are presented at the bottom. Standard errors are clustered at the installation-level and shown in the parentheses. ***, ** and * Significant at 1, 5 and 10 percent level, respectively.

Table 8: Estimations by Quartiles for Initial Group of Countries

	(1)	(2)	(3)	(4)	(5)	(6)
Post 2015						
× Allowances (Q_1)	0.0889***	0.0733***	0.0844***	0.0766***	0.0533***	0.0508***
	(0.0194)	(0.0194)	(0.0192)	(0.0190)	(0.0195)	(0.0194)
× Allowances (Q_2)	0.0348***	0.0280***	0.0355***	0.0304***	-0.000914	-0.00185
	(0.0106)	(0.0104)	(0.0103)	(0.0103)	(0.00962)	(0.00949)
× Allowances (Q_3)	0.0314***	0.0285***	0.0323***	0.0285***	-0.00698	-0.00704
	(0.00764)	(0.00733)	(0.00738)	(0.00740)	(0.00726)	(0.00722)
× Allowances (Q_4)	0.0352***	0.0332***	0.0359***	0.0353***	-0.000652	0.00385
	(0.00633)	(0.00605)	(0.00607)	(0.00655)	(0.00613)	(0.00651)
Allowances (Q_1)	-0.0489***	-0.0194	-0.0325**	-0.0294*	0.0275	0.0248
	(0.0161)	(0.0155)	(0.0153)	(0.0153)	(0.0170)	(0.0170)
Allowances (Q_2)	0.0169	0.0348***	0.0192*	0.0220*	0.0666***	0.0648***
	(0.0124)	(0.0115)	(0.0114)	(0.0114)	(0.0115)	(0.0115)
Allowances (Q_3)	0.0277**	0.0385***	0.0247*	0.0293**	0.0846***	0.0843***
	(0.0141)	(0.0134)	(0.0133)	(0.0134)	(0.0129)	(0.0129)
Allowances (Q_4)	0.0730***	0.0686***	0.0523***	0.0580***	0.108***	0.107***
	(0.0103)	(0.0102)	(0.0105)	(0.0103)	(0.0105)	(0.0103)
Post 2015	-0.615***	-0.299***				
	(0.0648)	(0.0592)				
Electricity Demand		7.030***				
		(0.297)				
Observations	29810	29810	29810	29810	29810	29810
Plant FEs	Yes	Yes	Yes	Yes	Yes	Yes
Year FEs	No	No	Yes	No	No	No
Country-Year FEs	No	No	No	No	Yes	Yes
Fuel-Year FEs	No	No	No	Yes	No	Yes
R-squared	0.905	0.909	0.911	0.912	0.916	0.918

Notes: The table shows the regression results from estimating the relationship between the allowances and emissions following the Paris Agreement for various quartiles of allowances size. The sample in these estimates consists of countries which have been initially the Member States before significant enlargement: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain and Sweden. Dependent variable is the natural logarithm of emissions. Allowances (Q) with numeric subscripts denote the natural logarithm of the allowances allocated to the installations in each quartile. Post 2015 is a dummy variable taking the value of 1 for the 2016-2022 period, and zero for the period 2010-2015. Electricity demand denotes the country-level electricity demand per capita. The list of fixed effects are presented at the bottom. Standard errors are clustered at the installation-level and shown in the parentheses. ***, ** and * Significant at 1, 5 and 10 percent level, respectively.

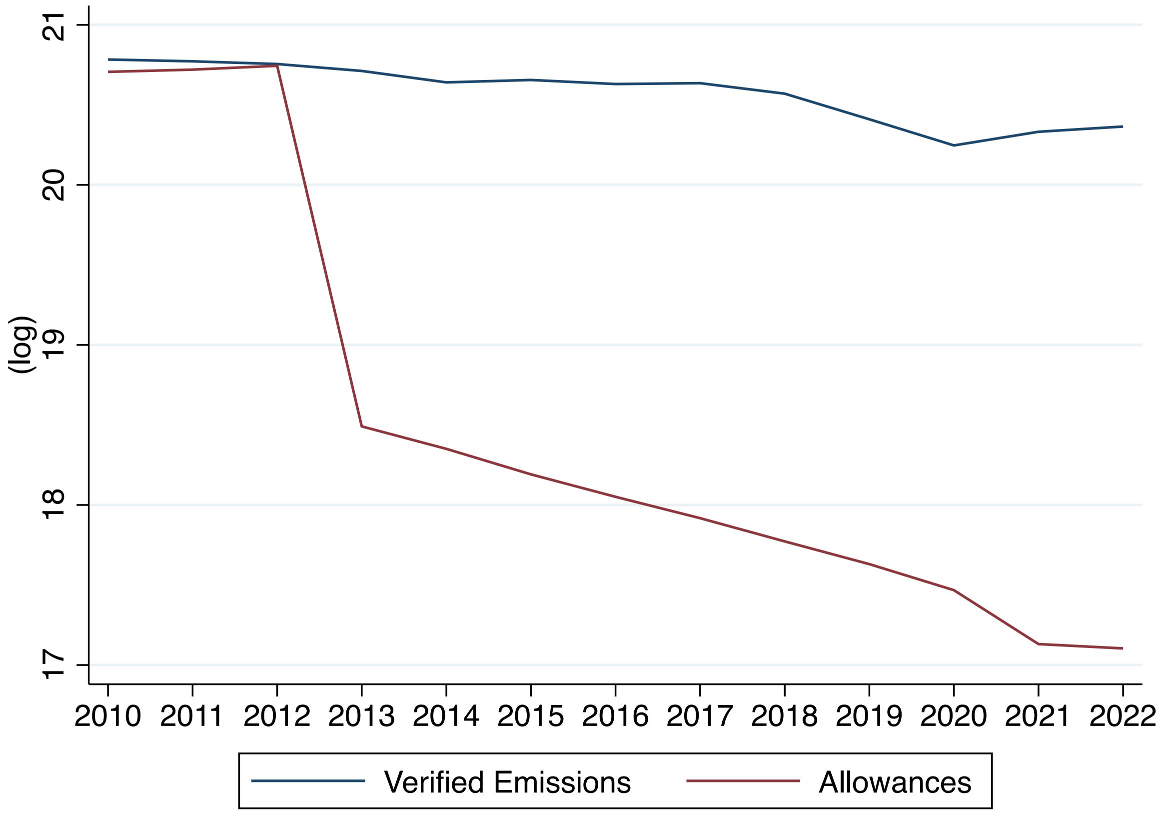
Table 9: Estimations by Quartiles Enlargement Group of Countries

	(1)	(2)	(3)	(4)	(5)	(6)
Post 2015						
× Allowances (Q_1)	0.0827	0.0786	0.120	0.106	0.106	0.0974
	(0.0790)	(0.0823)	(0.0872)	(0.0872)	(0.0763)	(0.0735)
× Allowances (Q_2)	-0.0236	-0.0217	-0.000896	-0.00867	0.0283	0.0240
	(0.0276)	(0.0268)	(0.0281)	(0.0281)	(0.0282)	(0.0284)
× Allowances (Q_3)	-0.0271*	-0.0253*	-0.00782	-0.0117	0.000128	-0.00472
	(0.0146)	(0.0145)	(0.0148)	(0.0148)	(0.0143)	(0.0147)
× Allowances (Q_4)	-0.0119	-0.0109	0.00497	0.000755	0.000540	-0.00371
	(0.0116)	(0.0116)	(0.0118)	(0.0124)	(0.0117)	(0.0125)
Allowances (Q_1)	-0.189**	-0.186**	-0.207**	-0.203**	-0.206***	-0.211***
	(0.0764)	(0.0782)	(0.0849)	(0.0844)	(0.0745)	(0.0739)
Allowances (Q_2)	0.0967**	0.0987**	0.0633	0.0667	0.0498	0.0471
	(0.0433)	(0.0437)	(0.0438)	(0.0438)	(0.0450)	(0.0443)
Allowances (Q_3)	0.0969***	0.0889***	0.0536**	0.0593**	0.0418	0.0455*
	(0.0259)	(0.0258)	(0.0252)	(0.0259)	(0.0264)	(0.0265)
Allowances (Q_4)	0.108***	0.105***	0.0674***	0.0737***	0.0704***	0.0798***
	(0.0162)	(0.0160)	(0.0162)	(0.0179)	(0.0159)	(0.0178)
Post 2015	-0.0750	0.118				
	(0.129)	(0.137)				
Electricity Demand		-2.739***				
		(0.687)				
Observations	10740	10740	10740	10740	10740	10740
Plant FEs	Yes	Yes	Yes	Yes	Yes	Yes
Year FEs	No	No	Yes	No	No	No
Country-Year FEs	No	No	No	No	Yes	Yes
Fuel-Year FEs	No	No	No	Yes	No	Yes
R-squared	0.912	0.913	0.916	0.917	0.924	0.925

Notes: The table shows the regression results from estimating the relationship between the allowances and emissions following the Paris Agreement for various quartiles of allowances size. The sample in these estimates consists of countries entered the European Union with fifth (2004), sixth (2007) and seventh (2013) enlargement periods: Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, Bulgaria, Romania and Croatia. Dependent variable is the natural logarithm of emissions. Allowances (Q) with numeric subscripts denote the natural logarithm of the allowances allocated to the installations in each quartile. Post 2015 is a dummy variable taking the value of 1 for the 2016-2022 period, and zero for the period 2010-2015. Electricity demand denotes the country-level electricity demand per capita. The list of fixed effects are presented at the bottom. Standard errors are clustered at the installation-level and shown in the parentheses. ***, ** and * Significant at 1, 5 and 10 percent level, respectively.

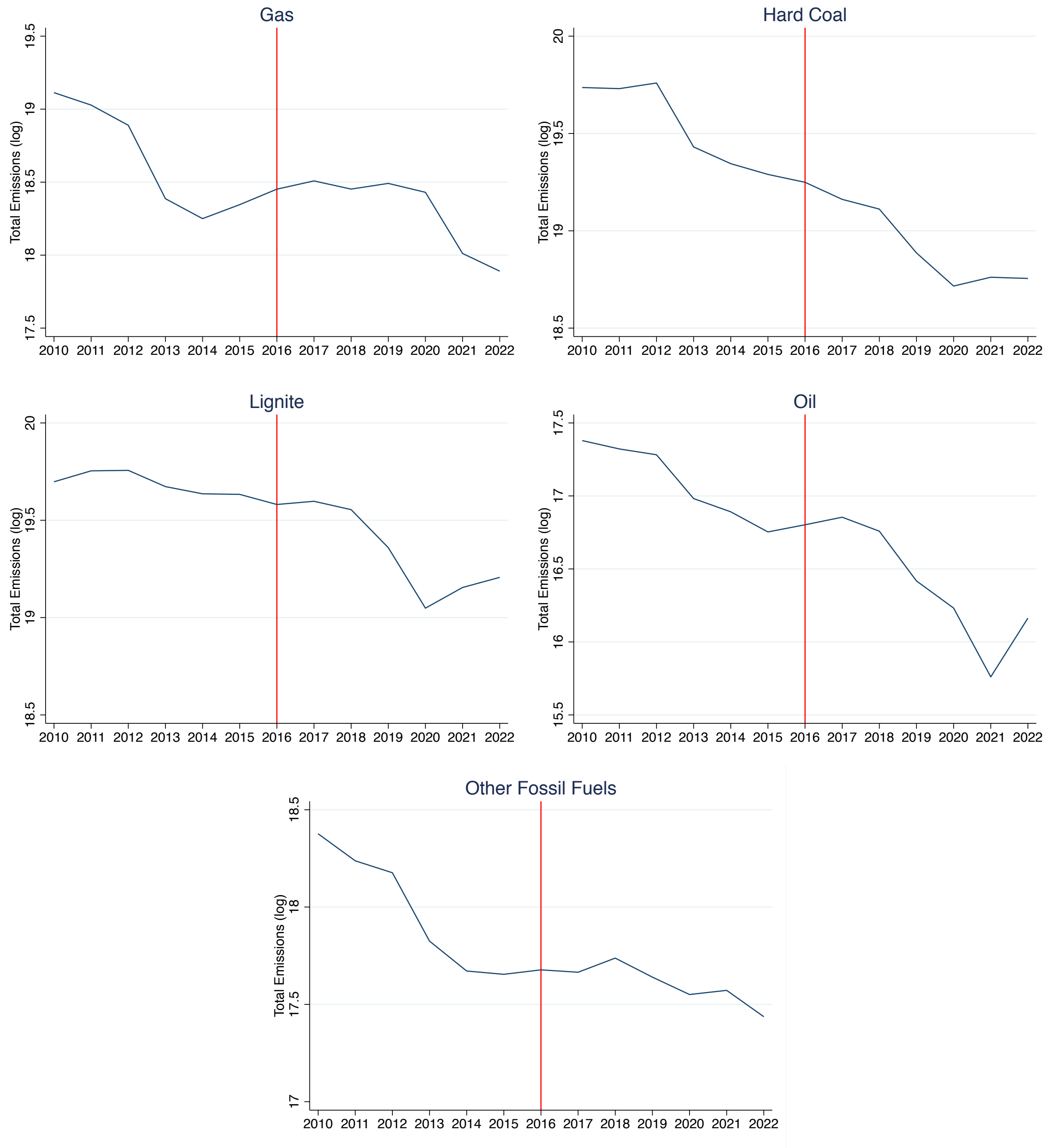
Figures

Figure 1: Emissions and Allowances



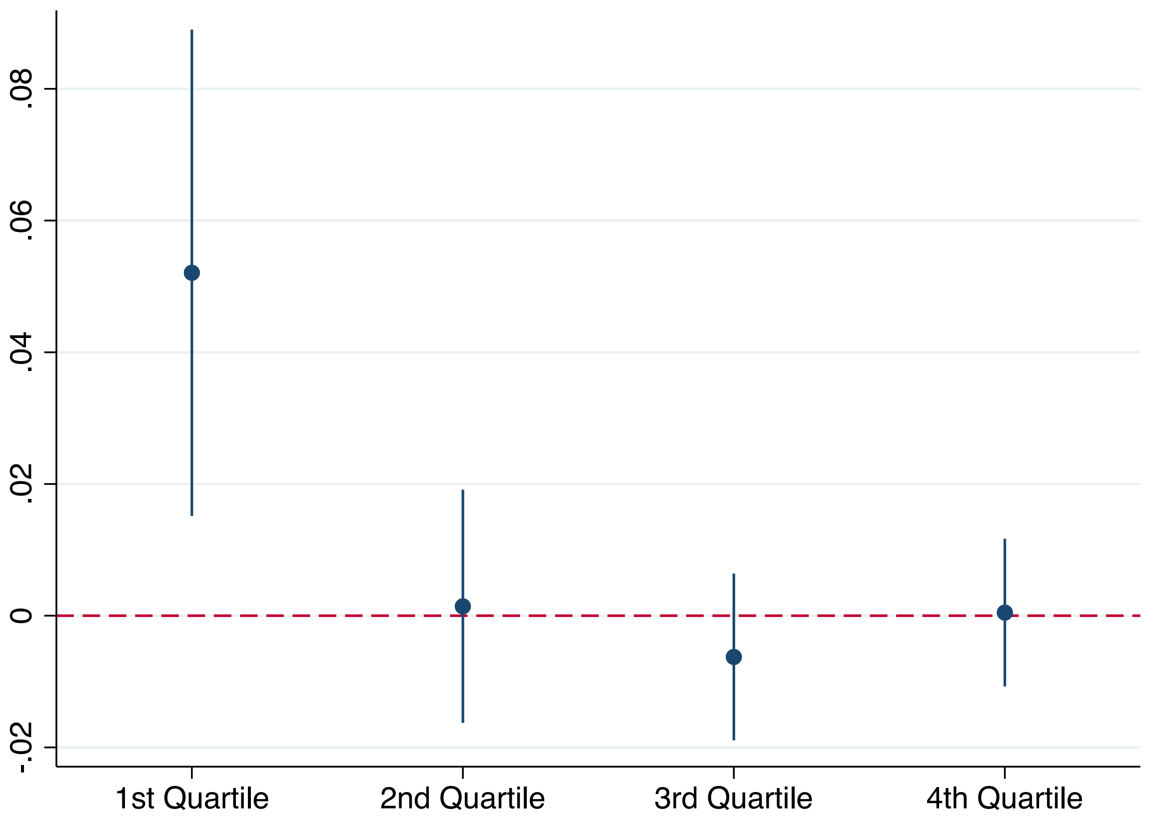
Note: This figure shows the emissions and allowances of the installations from power sector regulated under the EU ETS. The values are presented in natural logarithms.

Figure 2: Verified Emissions by Fuel Type



Note: This figure presents the verified emissions of installations aggregated for each fuel type: gas, hard coal, lignite, oil and other fossil fuels. The values are presented in natural logarithms. Vertical red lines indicates the first year following the Paris Agreement.

Figure 3: Emissions Reduction by Quartile Distribution



Note: The figure shows the results of φ^r from estimating Equation (4) in a graphical form. The coefficient estimates (in dots) and their 95% confidence intervals (vertical lines) are plotted along the X-axis.

A Appendix Tables

Table A1: List of Countries in the Dataset

Austria	Belgium	Bulgaria	Croatia
Cyprus	Czechia	Denmark	Estonia
Finland	France	Germany	Greece
Hungary	Ireland	Italy	Latvia
Lithuania	Luxembourg	Malta	Netherlands
Norway	Poland	Portugal	Romania
Slovakia	Slovenia	Spain	Sweden

Notes: This table shows the list of countries in the dataset where the installations are located.

Table A2: Relationship between the Emissions and Allowances Controlling for Lagged Allowances

	(1)	(2)	(3)	(4)	(5)	(6)
ln(Allowances)	0.0301***	0.0311***	0.0140***	0.0153***	0.0208***	0.0204***
	(0.00341)	(0.00338)	(0.00362)	(0.00363)	(0.00388)	(0.00393)
Electricity Demand		1.621***	-0.145			
		(0.187)	(0.190)			
Lagged Allowances (log)	0.455***	0.452***	0.439***	0.434***	0.428***	0.421***
	(0.0140)	(0.0141)	(0.0143)	(0.0144)	(0.0153)	(0.0153)
Observations	35637	35637	35637	35637	35637	35637
Plant FEs	Yes	Yes	Yes	Yes	Yes	Yes
Year FEs	No	No	Yes	No	No	No
Fuel-year FEs	No	No	No	Yes	No	Yes
Country-year FEs	No	No	No	No	Yes	Yes
R-squared	0.933	0.933	0.935	0.936	0.938	0.939

Notes: The table shows the regression results from the relationship between the allowances and emissions for the whole sample period of 2010-2022. Dependent variable is the natural logarithm of emissions. ln(Allowances) denotes the natural logarithm of the allowances allocated to the installations. Lagged Allowances (log) denotes the allowances in natural logarithm for the previous period. Electricity demand denotes the country-level electricity demand per capita. The list of fixed effects are presented at the bottom. Standard errors are clustered at the installation-level and shown in the parentheses. ***, ** and * Significant at 1, 5 and 10 percent level, respectively.

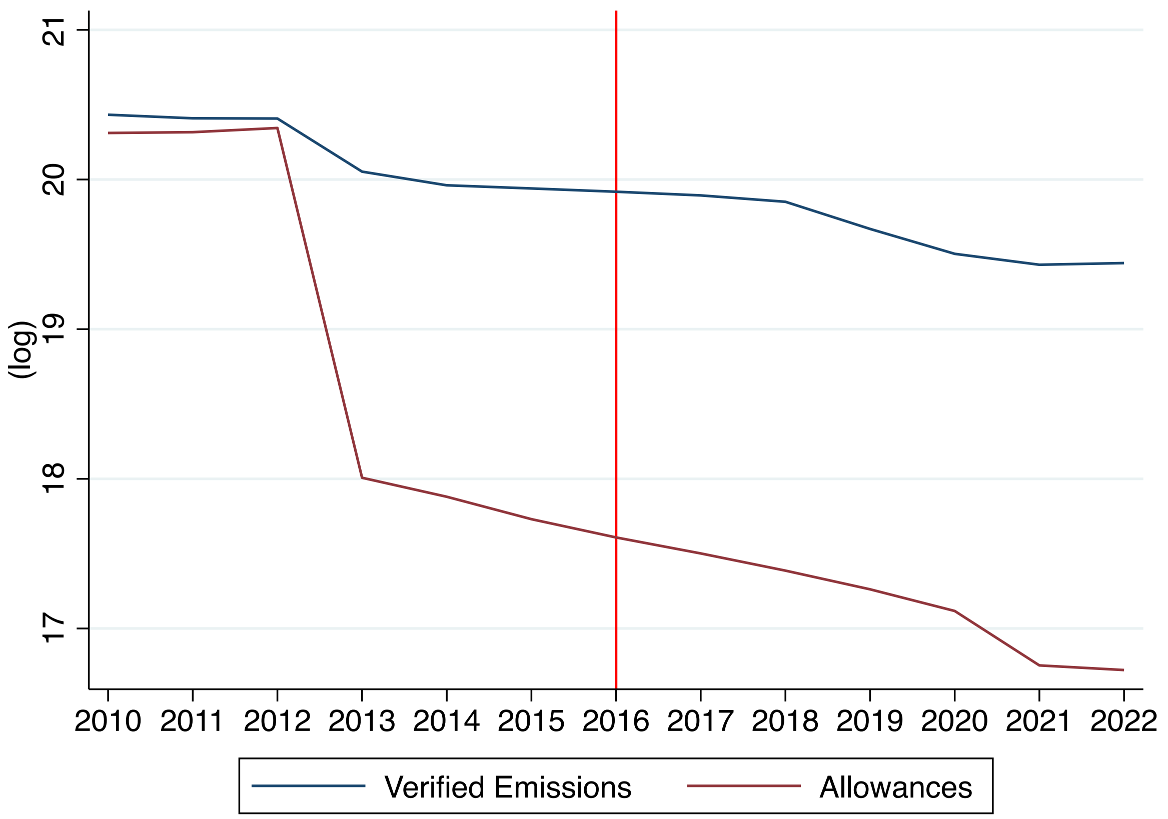
Table A3: Relationship between the Emissions and Allowances: Before and After the Paris Agreement

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Before Paris Agreement (2010-2015)						
ln(Allowances)	0.0351***	0.0414***	0.0247***	0.0293***	0.0587***	0.0600***
	(0.00657)	(0.00609)	(0.00624)	(0.00633)	(0.00695)	(0.00703)
Electricity Demand		9.700***	5.156***	5.010***		
		(0.415)	(0.449)	(0.458)		
Observations	21601	21601	21601	21601	21601	21601
Plant FEs	Yes	Yes	Yes	Yes	Yes	Yes
Year FEs	No	No	Yes	No	No	No
Fuel-year FEs	No	No	No	Yes	No	Yes
Country-year FEs	No	No	No	No	Yes	Yes
R-squared	0.926	0.933	0.936	0.936	0.939	0.939
Panel B: After Paris Agreement (2016-2022)						
ln(Allowances)	0.0644***	0.0613***	0.0433***	0.0389***	0.0419***	0.0358***
	(0.00796)	(0.00787)	(0.00764)	(0.00753)	(0.00770)	(0.00748)
Electricity Demand		3.257***	-0.450	-0.397		
		(0.283)	(0.383)	(0.401)		
Observations	18826	18826	18826	18826	18826	18826
Plant FEs	Yes	Yes	Yes	Yes	Yes	Yes
Year FEs	No	No	Yes	No	No	No
Fuel-year FEs	No	No	No	Yes	No	Yes
Country-year FEs	No	No	No	No	Yes	Yes
R-squared	0.941	0.942	0.944	0.945	0.946	0.948

Notes: The table shows the regression results from the relationship between the allowances and emissions for before (Panel A) and after (Panel B) the Paris Agreement separately. Dependent variable is the natural logarithm of emissions. ln(Allowances) denotes the natural logarithm of the allowances allocated to the installations. Electricity demand denotes the country-level electricity demand per capita. The list of fixed effects are presented at the bottom. Standard errors are clustered at the installation-level and shown in the parentheses. ***, ** and * Significant at 1, 5 and 10 percent level, respectively.

B Appendix Figures

Figure B1: Emissions and Allowances without Countries under Article 10c



Note: This figure illustrates the emissions and allowances of the installations from power sector regulated under the EU ETS. Countries subject to Article 10c which were allowed to receive free allowances are removed from the sample, i.e. the sample includes only auctioning installations. The values are presented in natural logarithms.

C Appendix Data

The variable "Electricity Generation and Net Imports" is comprised of the data from Eurostat, European Network of Transmission Systems Operators for Electricity (ENTSO-E) and U.S. Energy Information Administration (EIA). Regarding the variable "Installed Capacity", Ember gathers the information from Global Energy Monitor (GEM), International Renewable Energy Agency (IRENA) and World Resources Institute (WRI).