The effect of the EU ETS free allowance allocation on energy mix diversification: the case of Poland's power sector

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Abstract: Since 2013, power plants in the EU have been obliged to buy carbon permits instead of receiving them for free. However, in order to ease their energy transition, some Member States that meet certain conditions (mainly a high share of fossil fuels and low income) are allowed to continue to receive free allowances for existing power plants (Article 10c of the EU ETS Directive). In exchange, they must invest in modernizing their electricity sector and diversifying their energy supply. However, up to 70% of the conditional investments have been made in upgrading coal-fired units, which casts doubt on the effectiveness of the measure to increase energy diversification. This paper evaluates the effect that the so-called rule 10c has had on energy diversification. A synthetic control method is applied to aggregate data from Poland, one of the countries eligible for free allowances, to investigate how the lignite and wind share in electricity generation would have evolved had Poland not used the rule 10c derogation. Our results indicate that Poland's energy diversification would have been the same if allowances had been auctioned instead of allocated for free. Therefore, the policy is only relevant in political terms and involves unjustified revenue loss for affected governments in favour of installations, i.e. subsidies. Our results suggest that rule 10c, as defined, does not incentivize investment in low carbon alternatives. The use of this transitional free allocation will continue to be available in phase IV (2021–2030) of the EU Emission Trading System (EU ETS).

Key policy insights

- Application of the rule 10c derogation under the EU ETS, granting emission allowances for free to fossil fuel-reliant member states, has not achieved the intended goal of energy mix diversification in Poland.
- Using a synthetic control method, we show that the lignite and wind share of electricity production in Poland would have followed the same trajectory if full auctioning, instead of free allocation, had been applied.
- Because most conditional investments were used to retrofit coal-fired plants, the policy's main contribution was to subsidize continued use of coal power.
- The policy deprived affected governments of auction revenues that could have been used to ease decarbonization.

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1 Introduction

In theory, pricing emissions through emission trading or carbon taxation ensures abatement at the lowest cost and provides long-term incentives for low-carbon alternatives (Baumol and Oates, 1971; Baranzini et al., 2017). However, due to the increase in production costs that it entails, distributional and competitiveness concerns are the main barrier in terms of public support (Carattini et al., 2017) and optimal policy stringency (Verde et al., 2019). In emission trading systems, free allowance allocation is the main tool available to reduce compliance costs in contexts of high carbon intensity, so as to ease the low-carbon transition. This is especially sensitive in countries whose electricity production is heavily reliant on coal, the biggest contributor to climate change. For such countries, transitioning to a low-carbon energy system entails major economic and social impacts in terms of employment and capital returns. In these contexts, policy makers are often forced to make stringency adjustments—in terms of tax exemptions or free allowance allocation—to muster the necessary political support while promoting decarbonization investments.

The main aim of this paper is to empirically evaluate a free allowance allocation in this particular context, that of easing decarbonization investments in a heavily coal-dependent economy. The so-called rule 10c in the European Emission Trading System (EU ETS), named after Article 10c in the EU ETS directive, allows the allocation of emission allowances for free to power generators, instead of using default allowance auctioning, in countries where more than 30% of electricity is produced from a single fossil fuel and the GDP per capita is below 50% of the average EU level (EU Directive 2003/87/EC). Eight eligible Member States[1] have made use of rule 10c since its implementation in 2013. Installations in affected Member States can reduce their compliance costs and earn windfall profits by passing-through allowance opportunity costs (Fabra and Reguant 2014, Hitermann, 2016). In return, installations are required to invest at least the monetary market value of allocated allowances into diversification of the energy mix, clean technologies and retrofitting and upgrading their infrastructure. However, rule 10c investments should be made with the aim of eliminating the need for future use of rule 10c (EU 2011/C 99/03, OJEU 2011), meaning that Member States that were only eligible because of their high coal dependence should mainly invest in diversifying their energy mix[2].

However, as well as complaints about lack of transparency about the investments undertaken,

[1] Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Lithuania, Poland and Romania
[2] Bulgaria, Czech Republic, Hungary, Poland and Romania were eligible to apply rule 10c because of their high coal dependence.

it has been reported by several European NGOs that over 70% of 10c investments have been used to upgrade and retrofit the existing fossil fuel infrastructure (Carbon Market Watch, 2016; CAN et al., 2016). The relevant question here is whether these investments would *also* have occurred without rule 10c in place, that is, with the affected installations purchasing allowances instead of receiving them for free (and the Government retaining the corresponding revenue). This question can only be answered using a counterfactual approach, i.e., by proving that the trajectory of energy diversification would have been different without rule 10c. We use the case of Poland and focus on its share of lignite used for electricity production, as this is the most polluting type of coal. Poland is the main beneficiary of rule 10c and ranks top in CO_2 emissions within the EU ETS because of its heavy coal dependence.

To determine the possible trajectory of energy diversification, we use the synthetic control method (Abadie and Gardeazabal, 2003; Abadie et al. 2010, 2015), a methodology that has been receiving increasing attention having been used in many contexts for policy evaluation. This approach involves constructing a counterfactual (synthetic) country by means of a weighted combination of control units (other countries or regions where the policy is not implemented) that mimics the treated unit before the policy is implemented. The effect of the policy is then estimated by the difference between the affected country and its synthetic version after the policy is implemented. Key to the validity of this approach is that the synthetic (control) unit resembles the affected unit for a long enough period before the policy is implemented.

This method is increasingly being applied to environmental policies: Andersson (2019) analyses the case of the Swedish carbon tax and shows that the tax is behind an 11% reduction in carbon emissions as compared to a synthetic Sweden derived from a weighted average of OECD countries. Bueno and Valente (2019) show that a waste pricing policy in Trento (Italy) reduced unsorted household waste generation by 37.5% as compared to a synthetic Trento built from 19 control municipalities. Similarly, Bayer and Aklin (2020) show that EU ETS countries would have emitted more than 1 billion additional tons of CO_2 between 2008 and 2016 had the EU ETS not been implemented.

Here, we are interested in the use of lignite to produce electricity in Poland and how this has been affected by rule 10c (i.e. free allowances). We use aggregate data from 1992 to 2018 and construct a synthetic Poland by weighting control countries so that its average lignite share in gross electricity production mimics Poland's evolution before rule 10c implementation in 2013. The treatment effect is then displayed as the difference between the outcomes of Poland and the synthetic Poland.

This study is closely related to the study conducted by Zaklan (2016), where rule 10c is exploited as a natural experiment to research into the causal effect of allocations on emissions at the installation-level. Zaklan's results indicate that the allocation method makes no difference in terms of emissions. Our study deploys a similar empirical strategy to identify the treatment effect. However, we make use of aggregate instead of installation-level data and focus on evaluating whether the policy has succeeded in accelerating the reduction in the share of lignite in electricity production. Similarly, Kim and Kim (2016) use synthetic control to estimate the effect of a cap-and-trade system on the natural gas share in electricity generation in nine north-eastern US states, where a permit market has been implemented. Overall, their findings suggest that a transition from coal to gas has been promoted by the Regional Greenhouse Gas Initiative (RGGI). In contrast, our contribution concerns the effect of the allocation method (via rule 10c) on low-carbon technology adoption.

Our results are directly relevant to policy debates regarding the neutrality of the choice of allocation mechanism. In theory, the way allowances are allocated is independent of the allocation and therefore the location of emissions, the so-called independence property (Hahn and Stavins, 2011) that builds on the Coase theorem (Coase 1960)[3]. Although restricted to energy diversification in electricity production, our results point to the validity of the independence property in the EU ETS (as in Zaklan, 2016)[4]. This is a highly convenient property for mustering political support when cap-and-trade schemes are on the table as an instrument to address environmental issues.

However, the analysis also provides key information regarding the use of free allowance allocation as an instrument to ease decarbonization in coal-dependent countries. If retrofitting investments in coal plants are among the eligible investments that justify free permits, the increasing returns of coal plants may reduce the competitiveness of low-carbon alternatives, i.e., by increasing their opportunity costs. For instance, extending the lifetime of coal plants may be economically more attractive to shareholders than investing in renewables.

The use of free allowances may become critical as carbon markets emerge. In global terms, 43% of the world's population lives in countries where more than half of the electricity produced comes from coal sources (World Bank, 2020). This includes China, where 70% of electricity production comes from coal and its emission trading scheme is only in its early stages of operation: how China's coal plant fleet is managed within the scheme will be essential for the country to meet its climate goals, and the design of its allowance allocation will be key (IEA

[3] The Coase theorem implies that in a setting of bilateral negotiations, under certain assumptions a range of efficient outcomes can be accomplished, regardless of the initial distribution of property rights. Considering clean air as a property whose right is traded on a carbon market, any initial endowment of tradable rights (for example in the form of EUAs) does not affect the market equilibrium in a cap-and-trade system. Hahn and Stavins (2011) termed this the independence property.

[4] It should be noted that the independence property is usually defined at the installation level, whereas we used aggregate data. However, the finding that technology adoption is independent from allocation method at the aggregate level is in line with the effect operating at the more micro level.

2020).

Our paper proceeds as follows. Next section provides a description of the EU ETS and its relevant reforms and literature. Section 3 introduces the empirical methodology. Section 4 describes the data used. Section 5 presents the empirical analysis and results. Finally, section 6 concludes and discusses the main policy implications.

2 Background

The EU ETS was originally established in response to the 1997 Kyoto Protocol and undertakes a key function in the EU's efforts to meet its reduction targets. Today, it is the main policy instrument for curbing greenhouse gas (GHG) emissions. It is also the largest emissions permit market worldwide, covering almost half of the carbon dioxide (CO_2) emissions in the EU. Indeed, since the launch of the EU ETS in 2005, the number of ETS worldwide has been expanding. Today there are around 20 ETS in force, covering 27 jurisdictions across all scales, from local city to supranational level (International Carbon Action Partnership, 2019). Currently, the EU ETS covers 31 countries, comprising all 28 EU member states plus Iceland, Liechtenstein and Norway, and regulating emissions from around 13,500 power stations, industrial plants and airlines operating within the European Economic Area.

Power plants and other installations are part of this market, in which EU allowances (EUAs) are issued on the basis of a cap, set to the total maximum quantity of targeted CO_2 emissions. The carbon price is then conditional on the supply and demand of the permits in the market (see A1). By its nature, this carbon price favours less carbon-intensive fuels (nuclear and renewables) over more polluting ones (oil and coal).

The first trading period of this carbon market (from 2005 to 2007) was intended as a pilot phase before the first round of commitments under the Kyoto Protocol was about to start. Analogous to the binding Kyoto targets, the second period began in 2008 and ran until the end of 2012. As of January 2013, the EU ETS has been in its third phase and is currently looking ahead to its fourth trading period, Phase IV (from 2021 to 2030). Over the years since its implementation, the trading scheme has experienced several modifications, including the method of allowance allocation.[5]

2.1 Winning the lottery: free pollution permits

Since commencement of the EU ETS, the allocation of carbon permits has been carried out under a set of regulations that form the basis of the EU's cap-and-trade system, the EU ETS

[5] See Verde et al. (2019) for a comprehensive literature review of allowance allocation in the EU ETS

Directive[6], which has been amended several times during its operation, including the addition of the Linkage Directive that defines the relationship between EUAs and other tradable units under the Kyoto Protocol, the Aviation Directive and Directive 2009/29/EC.

During the first two emissions trading periods, most allowances were distributed for free. In addition, power generators were granted compensation for carbon-intensive assets, which also involved passing on allowance costs to end-users. Initially, this was not undesirable from the policy perspective. However, power producers took advantage of the situation and generated large windfall profits through allowances they had obtained free of charge. These additional carbon rents and their implications have been widely recognized and discussed (Veith et al., 2009; Pahle, 2010; Taschini and Urech, 2010; Keppler and Cruciani, 2010). At that time, a paper by Sijm et al. (2006) ignited the debate. They studied the implications of free CO_2 certificates on electricity generators and found that economic theory was partly corroborated as the opportunity costs of emissions trading were passed through to end-user prices, irrespective of costly or free allocation. Further analyses of cost pass-through from the EU ETS followed, which resulted in the identification of generally high rates of up to 100% and even more in several European electricity markets (Sijm et al., 2008; Lise et al., 2010; Fabra and Reguant, 2014; Hintermann, 2016). More importanly, where the potential for large windfall profits is tempting, investment decisions may be altered in favour of the maintenance of fossil fuels (Acworth et al., 2018).

These problems were recognised and, over time, the EU ETS has made progress towards an exclusively auction-based system for allowance allocation that is more consistent with the polluter-pays-principle and can be considered a more transparent and equitable approach (Woerdman et al., 2008).

2.2 The inciting incident: free allocation under rule 10c

From Phase III onwards, power plant operators have no longer been able to benefit from free allowance allocation. Instead, they have been required to buy allowances either at auction or on the secondary market. The expiry of free allocation in favour of full auctioning is expected to curb the possibilities of earning windfall profits (Carbon Market Watch, 2016). Whilst polluting power generators in EU15 countries must buy their emission rights by auction, eight out of ten eligible member states can make use of the derogation under Article 10c of the EU ETS Directive, aka rule 10c, provided that they meet one of the two required conditions: (i) poor or nonexistent connectivity to European electrical grid operated by the UCTE[7] or (ii) more

[6] Directive 2003/87/EC

[7] Union for the Coordination of Transmission of Electricity.

than 30% of the country's electricity generated from a single fossil fuel and GDP per capita below 50% of average GDP per capita of the Community. The eligible member states are lower-income countries that have joined the EU since 2004: Bulgaria, Cyprus, the Czech Republic, Estonia, Hungary, Lithuania, Poland and Romania[8].

These Member States are selected for a transitional period,[9] during which a fraction of the permits that have been intended for auctioning are allocated for free to power installations, implying that the affected Member States forego revenue from allowances otherwise auctioned. The stated objective of the policy is therefore to reduce costs for the electricity sector in the Member States where modernization plans are expected to be challenging, while easing a smooth transition to a low-carbon economy at a reasonable cost.

This optional free allocation is granted conditional on corresponding investments in modernization of the energy sector and diversification of the energy mix. Member States submit National Investment Plans (NIPs), specifying the investments to be implemented, with the aim of not being eligible for free allowances in the future, i.e. energy mix diversification is a must for countries that are eligible because their fossil fuel dependency is too high. The financial value of investments must be at least as high as the market value of the free CO_2 certificates that are allocated.

The European Commission has granted up to 680 million allowances that amount to more than EUR 12 billion in the period 2013 to 2019, of which EUR 7.4 billion solely apply to Poland. This makes Poland the largest beneficiary of the derogation. Marcu et al. (2018) estimate that over Phase IV an allocation of 660 million allowances is expected.

2.3 The case of Poland

Relative to the EU15, Poland's power generation sector is the most polluting. Despite shifting forces in the European market and tendencies to phase out coal, Poland faces a structural resistance to reduce coal use: besides a heavy reliance on coal for electricity and heat production, its regional economic dependence on coal and the high employment share of the coal sector play key roles. As a result, the Polish government provides support and backs the coal sector, and this in turn is supported by broad sectors of public opinion (Brauers and Oei, 2020).

There are also concerns regarding energy security. Given its large coal deposits, Poland is able to maintain a low dependency on energy imports, which are listed among the four lowest in the

[8] Although Latvia and Malta were also entitled to make use of the derogation, they decided not to do so.
[9] Recently, this period has been extended until at least 2030, in the context of the 2030 climate and energy framework.

European Union (EURACOAL, 2017). Given its substantial reserves, the consumption of hard coal and lignite is widespread across the country, accounting for up to 80% of electricity generation in 2018. Though hard coal is used for the majority of electricity production, lignite amounts to more than one third with almost all Polish lignite production being used in power plants (Widera et al., 2016). Classified as a low-rank, high-moisture type of coal, lignite is the most polluting grade of coal, with very high CO_2 emissions per unit of energy produced (Luo and Agraniotis, 2017).

The above situation means Poland has one of the slowest rates of emissions reductions under the EU ETS (Buckley et al., 2017).

2.4 Allowance allocation and technological change

The body of academic literature that examines the causal relationship between allocations and emissions is relatively small and is often focused on the independence property, by which emission outcomes are independent of the initial endowment of allowances. Reguant et al. (2008) examine whether the initial endowment of grandfathered allowances in Phase I affected the operational decisions of coal units in Spain. They cannot reject the credibility of the Coase theorem and provide evidence that firms' production decisions are not strongly linked to the initial allocation of permits under the EU ETS. In a more comprehensive study, Hahn and Stavins (2011) investigate the factors that affect the validity of the independence property within environmental cap-and-trade systems. In theory, transaction costs, market power, non-cost-minimizing behaviour and uncertainty are among the list of factors that may lead to distortions in allowance markets. When the effects of permit allocation on the performance of the EU ETS in particular are evaluated, the authors find strong support for the independence property. This is consistent with earlier findings reported by Fowlie and Perloff (2013), who undertook a similar study. They exploit a setting of exogenous change in the permit allocation rules of Southern California's Regional Clean Air Incentives Market (RECLAIM) that targets NOx and SOx emissions. They use an instrumental variable approach to investigate whether facility-level emissions are influenced by allocations and find evidence that the magnitude of initial allocation and production outcomes are independent.

However, as implied above, there are some conditions under which the property might not hold. Transaction costs and regulatory uncertainty in the permit market might violate the independence property (Stavins, 1995; Montero, 1998), but so would imperfect competition (Hahn, 1984). Using interview data on both ETS-regulated and non-regulated firms, Martin et al. (2013) ascertain a contradiction in the independence property with respect to technological change. Their findings suggest less innovation effort from firms that anticipated free allocation in Phase III. This is along the same lines as the results obtained by Hervé-Mignucci (2011), who found that planned investments in carbon-intensive power plants have been aborted in anticipation of auctioning as the default method of post-2013 periods. Given that firms are charged for allowances in the third trading period, Muûls et al. (2016) presume Phase III will have stronger effects on innovation.

The most recent data on EU ETS emissions from power plants report a decreasing trend. This evolution is partly attributable to European trends and measures to phase-out coal, which have led to a surge in low-carbon sources. Fuel-switching from coal to natural gas is considered a crucial factor and will gain in importance (Healy et al., 2018). In a previous study, Jaraite and Di Maria (2012) find that technological change is significantly related to carbon pricing. By analysing the environmental efficiency and productivity of fossil fuel-based energy production across EU member states, they considered well-designed allocation rules to be important for successful performance of the EU ETS. Wilson and Staffell (2018) describe the conditions that enable near-term fuel switching in coal-reliant countries. A higher, stable price for carbon is considered the primary incentive that promotes substitution of coal in the power sector. Other factors, including available fuel supply infrastructure or pre-built, but possibly underutilized, gas generation capacities, may also stimulate decarbonization efforts. Based on experiences from the United Kingdom, Wilson and Staffell (2018) acknowledge the potential for Germany's electricity production in relation to their sparsely used, existing gas-fired capacities. However, their results cannot be generalized and require a more thorough analysis of country-specific infrastructure, capacities, demand and other characteristics.

On the basis of this prior research, it is of interest to analyse whether the implementation of transitional free allocation, such as under EU ETS rule 10c provided the intended incentives and how it has affected Poland's high-carbon technology for power generation.

3 Methodology: the Synthetic Control Method

The Synthetic Control Method (SCM) is a comparatively new statistical approach that is closely related to the Differences-in-Differences framework. It was first proposed by Abadie and Gardeazabal (2003) and Abadie et al. (2010, 2015). Whereas the Differences-in-Differences model relies on the assumption that the effect of unobserved variables on outcome is time-invariant (i.e. pre-treatment trends are assumed to be parallel), the SCM allows for the presence of time-varying confounders. The method can be implemented at the aggregate level in a single or more units by using a synthetic cohort as a statistical counterfactual. To minimize the distance in pre-intervention characteristics between treated and untreated units, a convex combination or weighted average, respectively, of the control group is provided. The treatment effect (i.e. the specific policy's impact) is evaluated by taking a simple difference between the post-treatment outcome of the treated and untreated units. The selection of a control group that appropriately replicates the trend of the outcome variable is essential to study the treatment's effect on the unit of interest. In this regard, it is important to restrict the donor pool to countries that are thought to have similar underlying structural conditions determining the outcome variable as the case of interest (Abadie et al., 2020). The identification of the donor pool to synthesize the counterfactual requires the exclusion of entities that are equally affected by the policy as well as the inclusion of entities that have values of predictors similar to those of the treated unit before treatment. These requirements make the EU15 sample appropriate for the case of Poland[10].

Hence, in this study, the treatment of interest is the introduction of rule 10c as part of the EU ETS, under which Poland's power generation sector continued to receive free allowances, unlike countries that are part of the EU15. To estimate how the change in 2013 affected domestic energy production, we use the SCM and construct a counterfactual Poland that stimulates what the outcome would have been without the policy. Following Abadie and Gardeazabal (2003) and Abadie et al. (2010, 2015), we start the analysis by using a sample of J + 1 countries, where unit j = 1 corresponds to Poland and units j = 2 to j = J + 1 to the potential controls that form the donor pool. These controls correspond to a sample of the EU15 countries that have been affected by the change in allocation regime[11]. We assume that the dataset is a balanced panel, where all J + 1 countries are observed in the same T time periods; we refer to T0 as the pre-intervention period and T1 as the post-intervention period. The study uses annual country-level data for the period of 1992 to 2018. The derogation rule was introduced in Phase III of the EU ETS, therefore T0 represents the period from 1992 to 2012 and T1 the period from 2013 to 2018.

As specified above, the SCM provides a weighted average of the EU15 countries whose power generation sector is subject to full auctioning and does not fall under the derogation rule. The synthetic control is represented by a vector of weights $\mathbf{w} = (w_2, \dots, w_{J+1})'$, where $0 \leq w_j \leq 1$ for $j \in \{2, \dots, J+1\}$ and $\sum_{j=2}^{J+1} w_j = 1$. Referring to Mill's Method of Difference, Abadie et al. (2015) propose selecting the value of $\mathbf{w}$ such that the pre-treatment characteristics of the unit of interest are represented as best as possible by the synthetic unit. Therefore, we specify a vector of size k, $\mathbf{x}_1$, with observed pre-intervention characteristics for Poland and a $(k \times J)$ matrix $\mathbf{X}_0$ with the same variables for the donor pool. These predictors are used to build a synthetic

[10] Poland did not become a formal EU member State until 2004. However, the integration process started with Poland's application for membership in Athens in 1994.

[11] Since the object of the analysis is to evaluate the effect of rule 10c, we use Poland as the treated unit and EU15 as controls, even though, strictly speaking, the latter were the countries experiencing a change in the allocation regime. Key to the validity of the method is that the model is able to resemble the outcome trajectories before 2013. The effect is the difference between the two trajectories after 2013.

Poland as a convex combination of the EU15 that best describes the actual Poland in terms of pre-treatment values of lignite share.[12] The vector $\mathbf{x}_1 - \mathbf{X}_0\mathbf{w}$ corresponds to the difference between pre-2013 predictors for Poland and each unit in the donor pool. Consequently, let $\mathbf{w}^*$ be the vector of optimal weights that minimizes this difference and is chosen such that

$$w^* = arg \ \min_{w}[x_1 - \boldsymbol{X_0}w]'\boldsymbol{V}[x_1 - \boldsymbol{X_0}w],$$

where $\boldsymbol{V}$ is a $(k \times k)$ matrix that weights the pre-2013 predictors in accordance with their predictive power on the outcome (Abadie and Gardeazabal, 2003). The selection of a synthetic control that will appropriately reproduce the trend of the outcome variable is highly dependent on the selection of $\boldsymbol{V}$. Finally, we specify a vector $\mathbf{y_1}$ of size T_1 with post-treatment values of the outcome (i.e. lignite share) for Poland and a $(T_1 \times J)$ matrix $\mathbf{Y_0}$ with the same values of the outcome for the donor pool. The intervention's impact is evaluated by taking a simple difference between the outcome of the treated and the untreated units, $\mathbf{y}_1 - \mathbf{Y}_0\mathbf{w}^*$.

4 Data

The question of interest is to what extent rule 10c affected the lignite share in Poland's electricity generation after 2013. A key challenge in evaluating the impact of such an intervention is to determine what the outcome would have been without it. In our case, the starting point is to construct a synthetic counterpart of the country of interest as a convex combination of units in the control group that are not subject to the treatment, as outlined above. Hence, the donor pool for the potential controls comprised EU15 member states that have not been eligible for the derogation: Austria, Belgium, Germany, Denmark, Greece, Spain, Finland, France, Ireland, Italy, Luxembourg, Netherlands, Portugal, Sweden and the United Kingdom. Following Abadie et al. (2015), these countries are chosen for their ability to resemble the treated unit in terms of the pre-intervention characteristics that we expect to impact the lignite share of Poland. The treated unit as well as the potential controls are all member states of the EU. Therefore, we expect that countries forming part of this political and economic union are driven by similar structural processes.

The outcome variable of interest is gross electricity generation from lignite in thousand tonnes of oil equivalent (KTOE[13]) as a share of total gross production. Total gross production comprises gross generation from combustible fuels (solid fuels and natural gas among others), nuclear and other sources, and renewables, including hydroelectric power generation. To ensure that the potential controls resemble Poland's pre-2013 brown coal share as accurately

[12] See Section 4 and Table A1 in the Appendix for a detailed list of the covariates used.
[13] A standardized energy unit, by definition a kilotonne of oil equivalent, is equal to 11.62 gigawatt hours (GWh).

as possible, the covariates in vector $\mathbf{x}_i$ are selected based on the relevant applied literature. For the subsequent analysis, we consider two sets of covariates: (i) electricity production capacities (total, combustible fuels and hydro) and final consumption of electricity per capita to account for energy system full supply and demand and (ii) a set of macroeconomic variables that capture the relevant country's economic status: population, GDP per capita and total energy imports and exports.[14] Lagged lignite share (for 2012 and 2005) is also included in the list of predictors.[15]

To evaluate the change in fuel mix in power generation at the national level, the covariates in vector $\mathbf{x}_i$ have been selected based on the related theoretical and empirical literature as presented in Section 2 and their availability in the time period of interest. Note that the EU ETS operates at a more disaggregated level and an analysis directly targeting the effect on EU ETS-regulated installations is a more accurate approach. However, the necessary installation-level data on electricity production and emissions is confidential, so an investigation of the effect on installations is not feasible. The current study uses annual country-level data from the Eurostat database. A detailed list of variable definitions and data sources is provided in Table A1 in the Appendix. Rule 10c began in January 2013. The sample period in this paper extends from 1992 to 2018, which covers 21 pre-treatment periods and six post-treatment periods. Ideally, we would have a longer post-treatment period to be sure that the policy is able to break potential inertias in the electricity sector. Hence this caveat should be considered when interpreting our results.

5 Analysis

The selection of a synthetic control that closely reproduces the evolution of the outcome variable of the treated unit is essential to examine the treatment effect. In our case, the effect of derogation under rule 10c is quantified by a simple difference between the post-2013 outcome of Poland and its synthetic equivalent. The outcome variable of interest, y_{jt}, is the gross electricity generation from lignite (as a percentage of total gross production) for country j at time t.

[14] All covariates are transformed into natural logarithms to account for non-linear relationships between the dependent and independent variable.

[15] Contrary to the opinion of Cavallo et al. (2013), among others, who reasoned that one may include all pre-treatment lags of the outcome variable as predictors, we follow the alternative put forth by Kaul et al. (2015), using only the lag of the last pre-treatment period (2012) and another lag (2001).

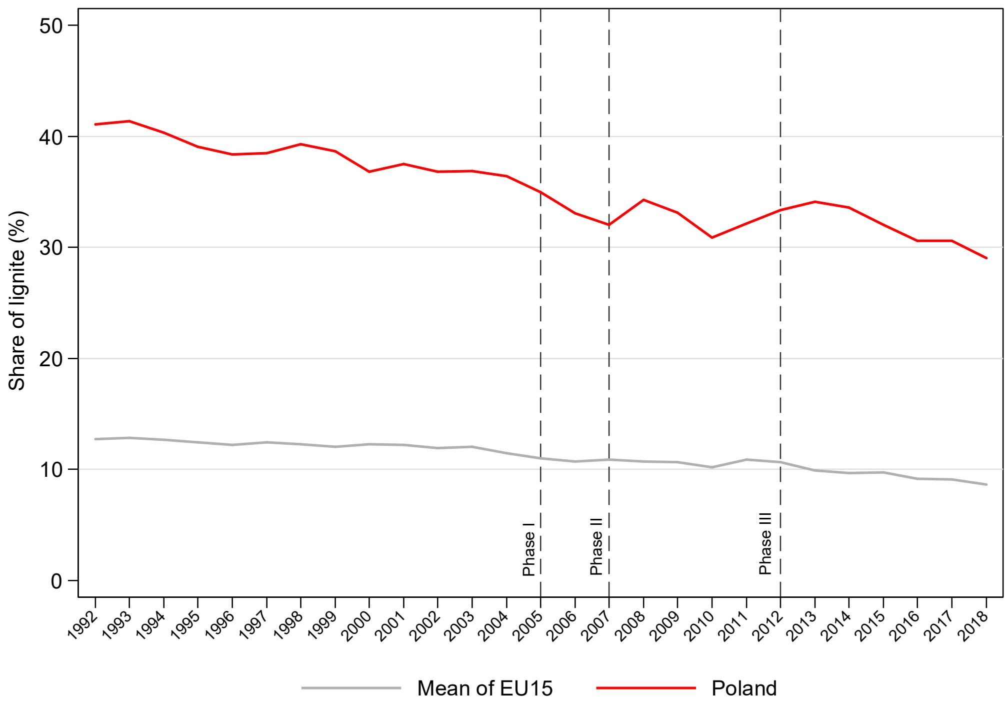

Fig. 1. Lignite share in power generation in Poland and EU15

Figure 1 depicts the evolution of lignite share in the electricity production of Poland and the donor pool from 1993 to 2016. Both regions are characterized by a falling trend. However, the illustration suggests that the EU15 is not an optimal control either for replicating Poland or the effect of the derogation. Consequently, we construct a counterfactual Poland as a convex combination of potential controls by choosing the vector of optimal weights $w*$, and we simulate the trend of lignite share in Polish power generation that is not exempt from full auctioning.

Table 1 displays the estimates of vector $w*$. The countries in the donor pool and the weight attached to each of them for the synthetic Poland are presented. A convex combination or weighted average, respectively, of Germany (56%), Greece (36%) and Portugal (7.9%) constitutes Poland's synthetic control, with the remaining EU15 member states contributing weights of zero.

Table 1: Country weights for synthetic Poland

Country	Weight	Country	Weight
Austria	0	Ireland	0
Belgium	0	Italy	0
Germany	0.567	Luxembourg	0
Denmark	0	Netherlands	0
Greece	0.358	Portugal	0,076
Spain	0	Sweden	0
Finland	0	United Kingdom	0
France	0		

Table 2 presents the lignite share predictor means in the pre-intervention period for Poland, its counterfactual and the average of the EU15 sample from 1992 to 2012. Basically, compared to the synthetic control, the average of the EU15 performs poorer in representing actual Poland's predictor means.

Table 2. Pre-2013 predictor means for Poland, synthetic Poland and the average of the donor pool

Variable	Poland	Synthetic Poland	Donor Pool
Ln population	17.46	17.36	16.45
Ln GDP per capita	12.32	13.49	10.31
Ln Electr. Final consump. per capita	7.99	8.57	8.75
Ln capacity total	10.29	10.67	10
Ln capacity combustibles	10.20	10.20	9.24
Ln capacity hydro	7.70	8.70	7.8
Ln imports	10.39	11.43	10.7
Ln exports	9.85	9.59	9.24
Ln indigenous production of lignite	11.03	10.82	3.20
Share of lignite (2012) (%)	33.36	32.58	6.85
Share of lignite (2005) (%)	34.96	35.14	7.64

Note: All variables except lagged lignite share are averaged for the pre-treatment period (1992–2012); missing data are ignored. The last column displays an unweighted average for the 15 EU member states in the donor pool.

5.1 Empirical results

Figure 2 shows the evolution of gross generation from lignite over total production (in percent) in Poland and its synthetic counterpart from 1992 to 2018. Before the introduction of the derogation, Poland and its counterfactual display relatively similar trends. A measure indicating the overall pre-treatment fit between the evolution of the outcome variable for the treated unit and the synthetic control is the Root Mean Square Prediction Error (RMSPE) (Abadie et al., 2010). Recall that **V** weights the pre-2013 predictors in accordance with their predictive power on the outcome, which is tantamount to the minimization of the RMSPE of the outcome variable. In our case, the pre-2013 RMSPE is 0.99. Compared to synthetic Poland, the trend of Poland's actual lignite share deviates sizably after the rule 10c implementation period. Though the lignite share started to increase in 2010, year 2013 was a turning point. Since then, the use of lignite for gross electricity generation has been on a downward trajectory.

Fig. 2: Evolution of lignite share (as a percentage of power generation) between 1992 and 2018: Poland and Synthetic Poland. Note: The vertical dashed line marks the commencement of rule 10c Derogation.

Compared to the synthetic control, the decrease in Poland's actual share of lignite is less pronounced in the post-treatment period. Figure 3 plots the difference between the outcome of Poland and its synthetic counterpart, which illustrates the effect of the intervention on gross electricity generation from lignite. The post-treatment gap after introduction of rule 10c is up to 5.68 percentage points higher than its counterfactual. Hence, synthetic Poland experiences a stronger decrease in its gross generation from lignite under full auctioning. On average, this decrease is only 3.97% greater.

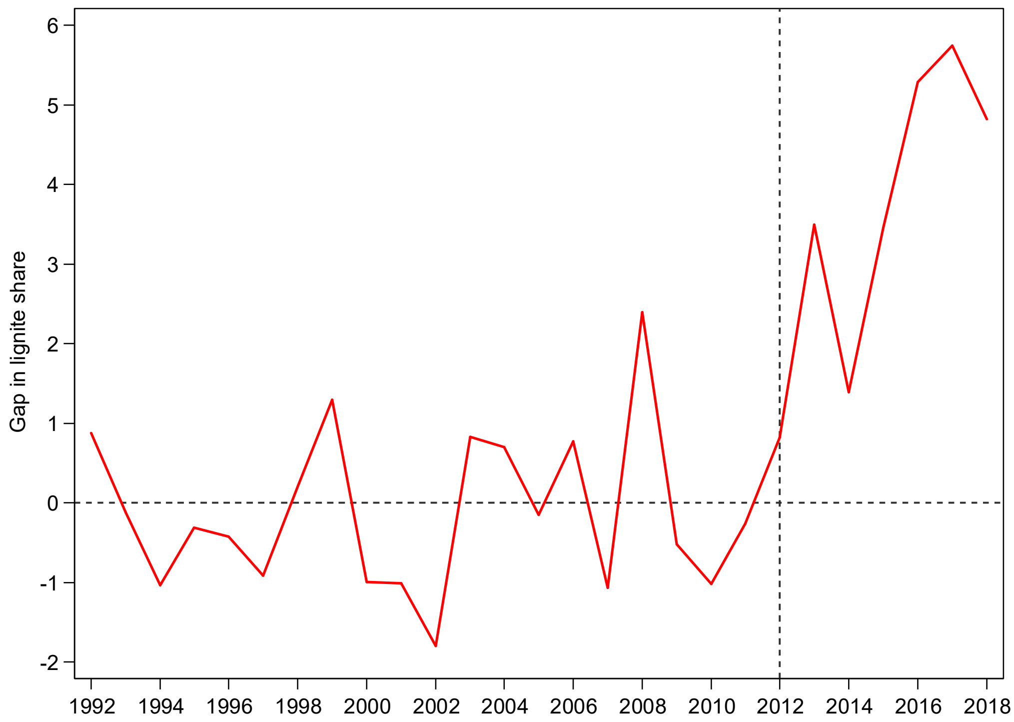

Fig. 3. Lignite share gaps (in percentage points of power generation) between Poland and synthetic Poland. Note: the vertical dashed line marks the commencement of rule 10c Derogation. The horizontal dashed line marks 0 difference between synthetic and real Poland.

5.2 Placebo tests and robustness checks

The previous findings suggest that in derogation from full auctioning, Poland's lignite share in electricity production did not follow exactly the path that may have been politically intended. Indeed, it suggests that rule 10c prevented Poland from further energy diversification. However, it is debatable whether the difference shown in Figure 3 is due to the derogation or to the inability of our synthetic control to replicate the trend of the outcome variable in the absence of the intervention. We want to test whether the post-treatment effect could have been sheer coincidence. The SCM does not calculate any statistical tests of significance and Abadie et al. (2010) indicate that standard procedures used to draw inference from large samples compare unfavourably to an application in comparative case studies with few control units. In order to check the robustness of our results, we conduct several types of placebo tests and check the sensitivity of our analysis. The ensuing results suggest how the lignite share would evolve if control units responded as if they had made use of the derogation. In line with Abadie et al. (2015), we first reassign the treatment period to 2007, a period before the derogation was introduced. In order to rule out any effects of the actual treatment period (2013), the sample period for this placebo test omits observations from later years. We include the same covariates and one outcome lag for 2006 instead of 2012. A large placebo effect would undermine our confidence in previous results. Figure 4 depicts the trend in Poland's lignite share and its control when the (placebo) derogation came into force in 2007, that is, at the end of the first trading period, and six years before the actual treatment period took place. Since there was no derogation from 2007 to 2013, there should not be any significant difference between the outcome variables. According to a visual inspection, there is less variation with regard to the pre-treatment period. Furthermore, the RMSPE amounts to 0.94. Part of the approximation may arise from the mere fact that Germany received marginal lower weight in the 2007 placebo test, to the advantage of Greece and Portugal.[16]

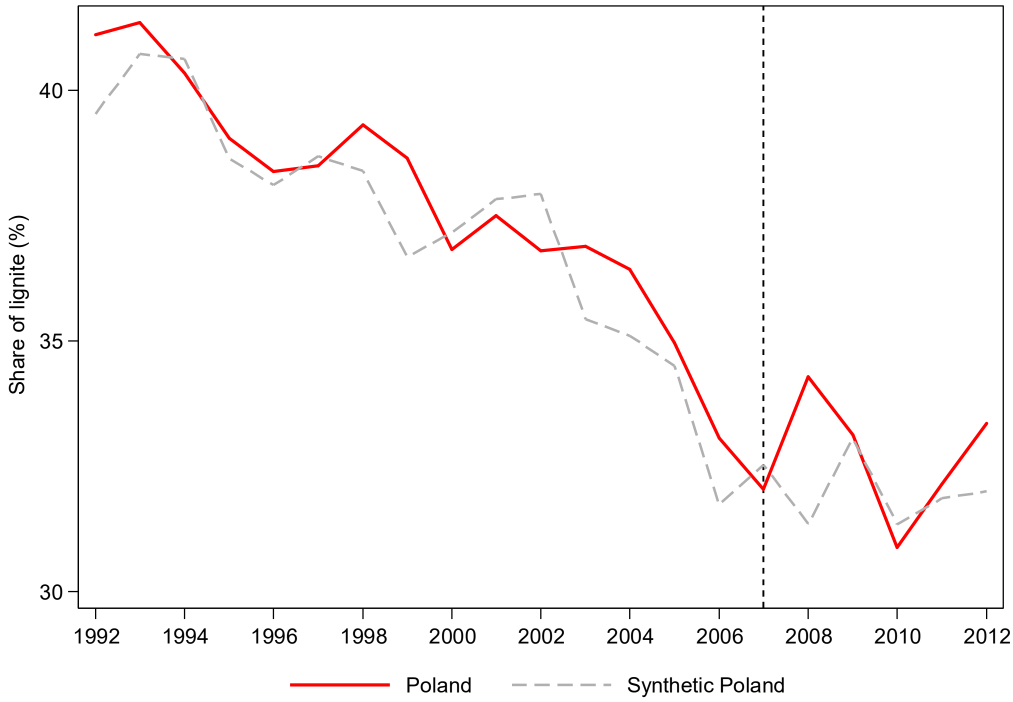

Fig. 4. In-time placebo test: Placebo rule 10c Derogation in 2007 and lignite share gaps (in percentage points of power generation) between Poland and synthetic Poland. Note: the vertical dashed line marks the commencement of rule 10c.

The in-space placebo test is a further inferential technique proposed by Abadie et al. (2015) that uses the ratio of the post- to pre-treatment RMSPE to make inferences from quantified differences in the outcome variable of interest between each treated unit and its synthetic control. In our case, this placebo test is only conceptually sensible if limited to countries with a positive lignite share. Otherwise, we would be trying to predict lignite share in countries

[16] Germany's weight to constitute Poland's synthetic control in the 2007 placebo test decreased to 0.5; while Greece and Portugal increased to 0.37 and 0.12, respectively

where there is no use of lignite. This is a drawback in terms of our capacity to make statistical inference as it reduces the sample significantly. However, the test results are still informative in qualitative terms. Figure 5 displays the ratios of post- to pre-treatment RMSPE for Poland and the sample of six countries with positive lignite share: Austria, Germany, Greece, Spain, France and Italy. Compared to these countries, Poland clearly shows the highest RMSPE ratio, with a post-2013 gap that is more than 5 times larger than before the derogation became effective. Abadie et al. (2015) state that a *p*-value can be calculated using the empirical distribution of the ratios: if one were to assign rule 10c at random in the data, the probability of obtaining a ratio at least as large as the one obtained for Poland is 1/7 ≈0.14 (i.e. the *p*-value). This test is therefore underpowered and hence we cannot conclude whether the effect is statistically significant. Notwithstanding this limitation, given the magnitude of the estimated effect for Poland compared to the distribution of placebo effects, we can conclude that the estimated impact of the derogation is likely to have been a coincidental effect.

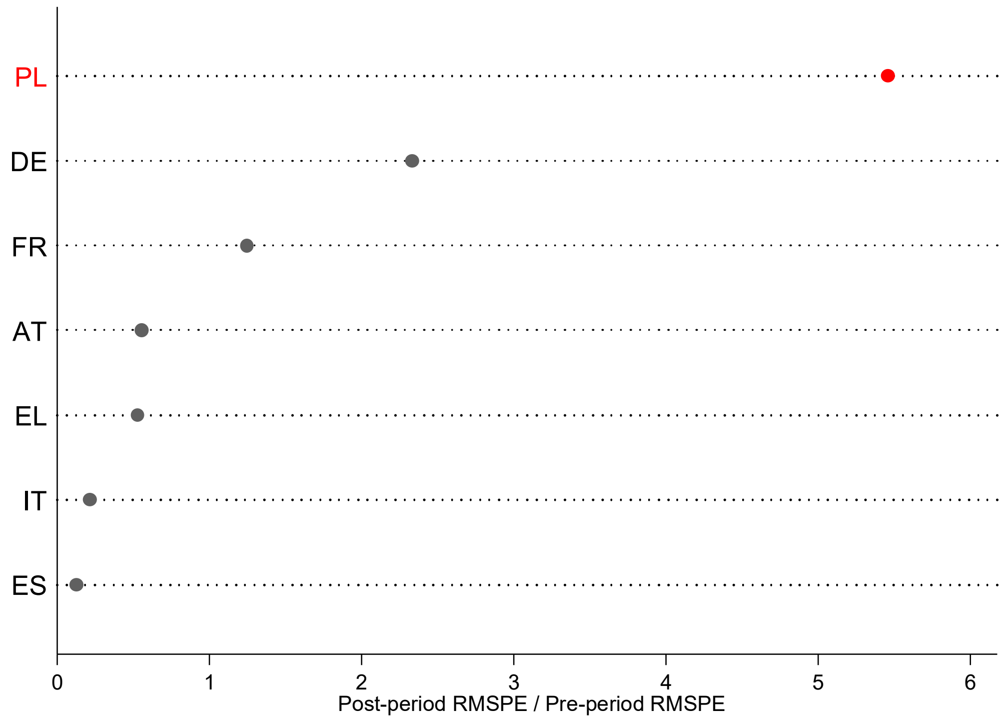

Fig. 5. In-space placebo study: Ratio of Post-Derogation RMSPE to Pre-Derogation RMSPE: Poland (PL) and EU15

The final sensitivity analysis evaluates how changes in the country weights, $\mathbf{w}^*$, affect our baseline results. We apply a leave-one-out robustness test based on iteratively re-running the SCM, each time removing one of the control units from the restricted donor pool. Recall that Poland's synthetic control comprised Germany, Greece and Portugal with greater weights attached to Germany and Greece. In this test, one of them is excluded from the restricted donor pool for the given iteration and the effect of the derogation is re-estimated. Figure 6 displays the ratios of post- to pre-treatment RMSPE without Germany or Greece. The ratio for Poland does not stand out anymore, suggesting the result is not robust to the exclusion of any these countries.

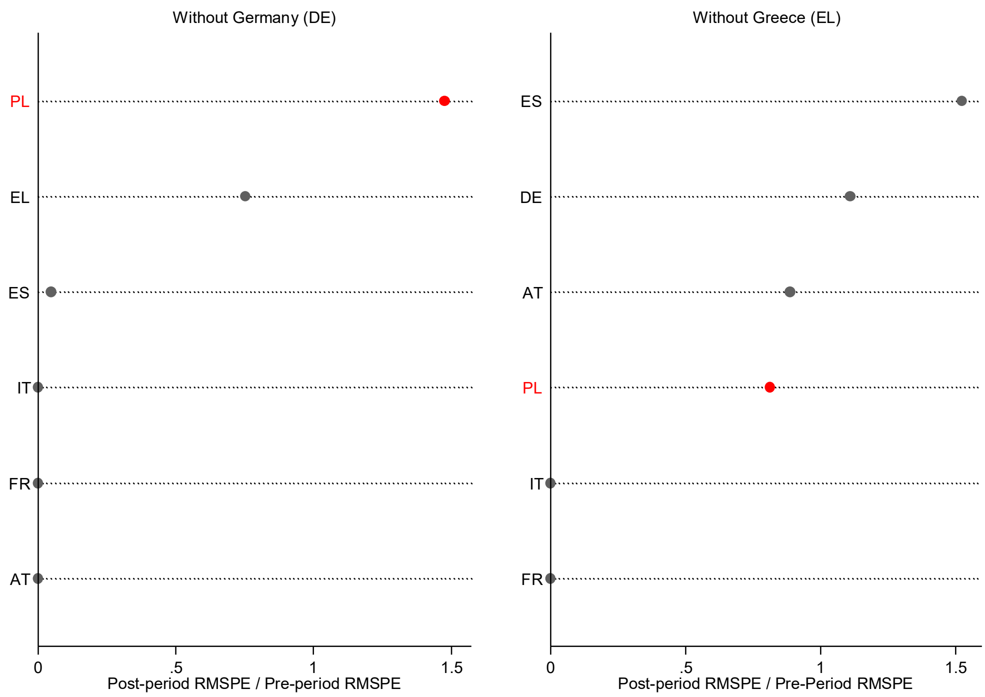

Fig. 6. In-space placebo study: Ratio of Post-Derogation RMSPE to Pre-Derogation RMSPE: Poland (PL) and EU15 without Germany (left panel) Greece (right panel)

Overall, we compared a set of placebo effects to the actual effect estimated for Poland. In general, one can conclude that if the placebo tests result in placebo treatment effects greater than that estimated for the treated unit, we can reject the hypothesis that there is any statistically significant evidence of a treatment effect. In our case, we do not have enough statistical power to make statistical inference. However, both the magnitude of the effect found and the differences in post to pre-RMSPE ratio between Poland and the other countries, especially when removing Greece, suggest that rule 10c did not make the intended difference in terms of the share of lignite in the electricity production. Note that neither idiosyncratic shocks nor other factors driving the derogation's impact can be ruled out by conducting placebo studies. Hope (2016) applies an additional difference-in-differences estimation to add credibility to his main findings. In contrast to his study, we cannot assume that unobserved heterogeneity is constant over time nor that it is uncorrelated with the policy intervention. Unobserved confounding variables, such as energy intensity or efficiency, would lead to biased estimates.

5.3 Wind farms

Our analysis suggests that rule 10c played no key role in the reduction of the lignite share of electricity production in Poland. However, this does not fully rule out the possibility that the policy had some effect on increasing the renewables share. For instance, it could be the case that while lignite share has been unaffected by the policy, the renewables share has increased because of the availability of resources eased by rule 10c. To account for this, we replicate the analysis using the share of wind in electricity generation as the outcome variable, as wind is the second most important source of energy after coal in Poland (IEA, 2020).

In recent years, the use of wind power has increased remarkably in Poland as a source of electricity: from 1% in 2010 to about 8% in 2018 (Eurostat, 2020). However, the increase in wind power, and in renewables in general, has also been intense throughout the EU and globally. Figure 7 shows how different the trajectory of the wind share in gross electricity production in Poland would have been if rule 10c had not been implemented. As is the case for the share of lignite, rule 10c appears to have played no significant role in increasing the wind share[17]. On the contrary, there seems to have been a lower increase in real Poland as compared to synthetic Poland (-3.5% in 2018); however, the difference is not statistically significant (Figure 8)[18]. This reinforces the main result of the analysis.

[17] See the appendix for the corresponding tables for country weights and pre-2013 predictor means (Tables A2 and A3).
[18] For wind share, we do not need to restrict the sample for this test as all countries have some positive wind share. We can therefore state the effect is not statistically significant.

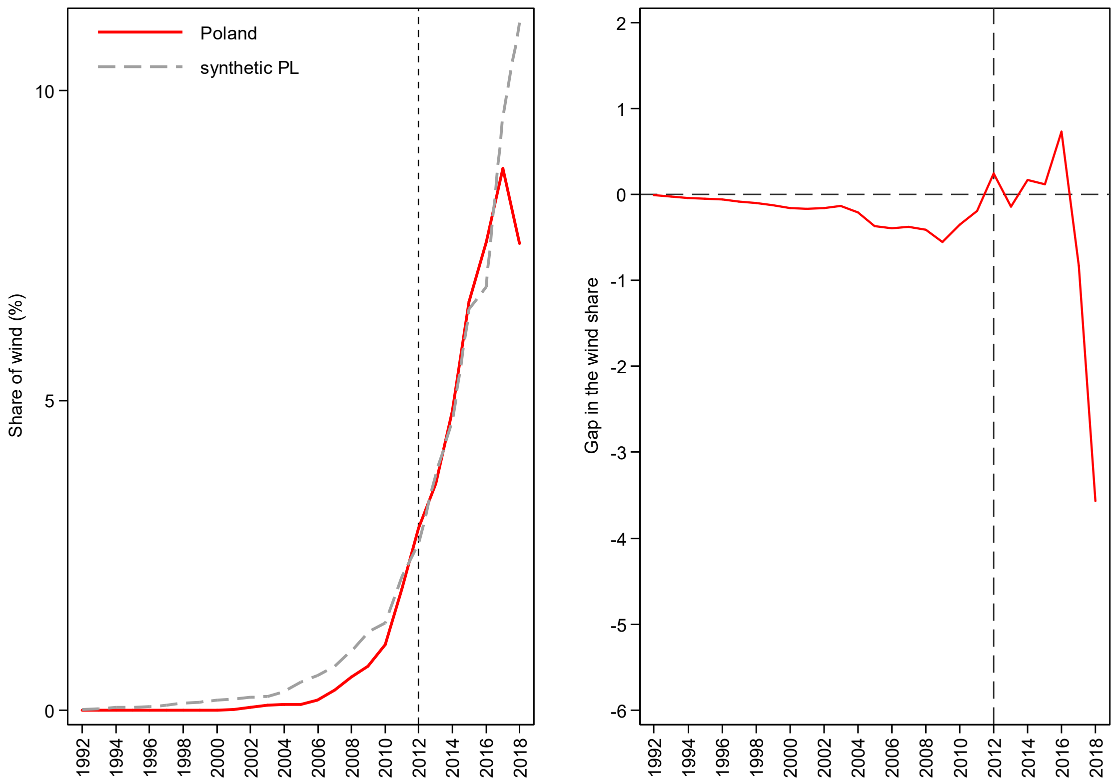

Fig. 7. Evolution of wind share (left) and wind share gaps (right) in percentage points of power generation between Poland and synthetic Poland. Note: the vertical dashed line marks the commencement of rule 10c.

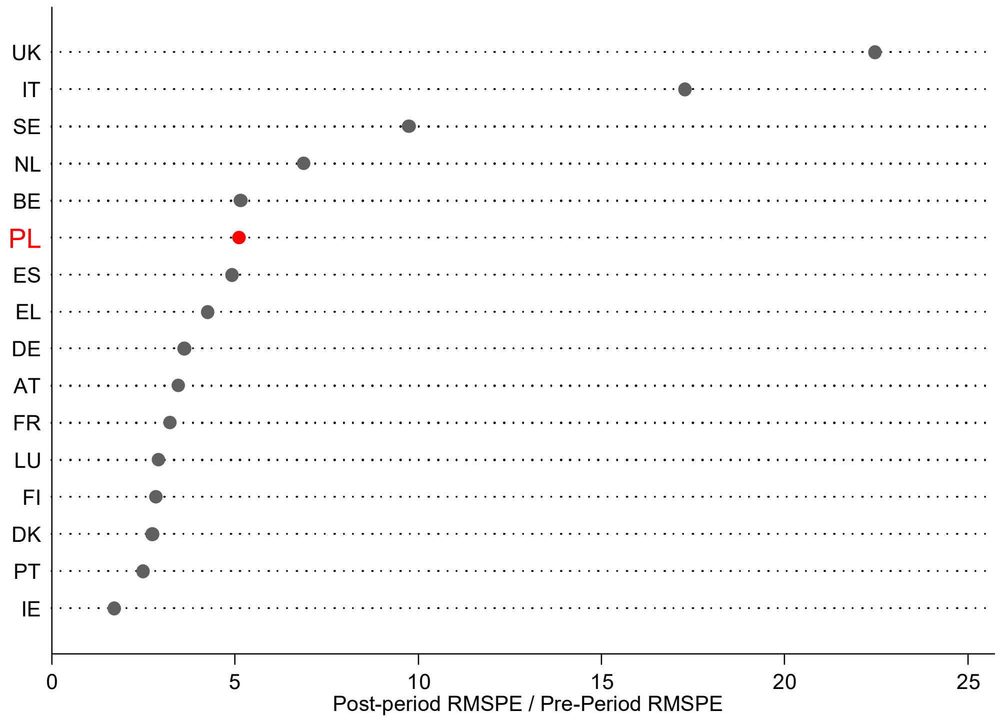

Fig. 8. In-space placebo study for wind share: Ratio of Post-Derogation RMSPE to Pre-Derogation RMSPE: Poland (PL) and EU15.

6 Discussion and Conclusions

For the purpose of facilitating the transition towards a more diversified portfolio of fuels in the power generation sector and to modernise existing energy infrastructure, a derogation rule under Article 10c of the EU ETS Directive was implemented in 2013 to countries with high fossil fuel dependence. Beneficiaries are exempt from full auctioning of carbon permits in order to facilitate low-carbon investments. This paper analyses the impact of this transitional free allocation on diversifying the energy mix. We particularly focus on the impact on the lignite share in total electricity production in Poland, a lignite-abundant economy and the largest beneficiary of the derogation. Using aggregate data and by application of a synthetic control approach, we find that the derogation in Phase III did not significantly affect energy diversification in the way that was intended. The lignite share declined as it would have done without receiving allowances for free. We replicate the analysis for the trajectory of wind power, the second most important source of electricity generation in Poland after coal, and also find that the wind share would have increased to the same extent without rule 10c. In summary, rule 10c did not have the intended effect of reducing fossil fuel dependence and hence free allowances cannot be justified in terms of Article 10c of the EU ETS directive. Rather, this Article has mainly acted as a subsidy to the power sector in coal dependent countries.

One potential mechanism of this lack of effect on energy mix diversification is that rule 10c, as defined in Phase III, allowed the refurbishing of coal power plants. While improving coal-fired carbon-efficiency, this also increased the opportunity costs of low-carbon alternatives. In a country with a political economic structure strongly permeated by coal (see Brauers and Oei, 2020), this perverse incentive is particularly relevant and could hamper the phasing out of coal. In the light of Poland's actual investment plans, the implemented modernization of existing infrastructure may have happened at the expense of not decreasing domestic reliance on lignite for power generation (Kenig-Witkowska et al., 2015). In this regard, rule 10c has not helped to break inertias created by fossil fuel-based systems. The long-term effects of this could involve increasing the amount of future investments required to achieve low-carbon objectives (IEA 2013).

The design of allowance allocation is one of the most sensitive and controversial issues in carbon markets. Allowing free allowances to accommodate coal-dependent countries can help to reduce compliance costs while promoting, in exchange, low-carbon investments. However, if not properly designed, this can turn into incentives that may lock-in investment into fossil fuels, hampering carbon objectives in the long term. According to their National Investment Plans, Poland is not the only country that has invested most of its rule 10c resources into retrofitting fossil fuel plants: In Romania, 20 out of 29 projects have supported fossil fuel energy production (gas, hard coal and lignite) and in the Czech Republic almost half of the investments have supported coal-fired installations (Carbon Market Watch 2016; Sandbag, 2019). Importantly, these countries' governments forewent the corresponding allowance auctioning revenues and, therefore, one can conclude that electricity producers were indirectly subsidized to make modernization investments in fossil fuel-based plants.

Our study contributes to the literature on the impact of free allocation on a country's prevalent energy mix. Although conclusive evidence is still lacking for the allocation regime associated with Phase III of the EU ETS, setting the right incentives for low-carbon investments are required to succeed in the energy transition and corresponding climate goals, especially in coal-dependent countries.

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Appendix

Table A1. Variable definitions and data sources

Variable	Data source
Total gross production and gross electricity generation by source of fuel, main activity electricity producer only, in thousand tonnes of oil equivalent	The Eurostat Dissemination Database, August 2020
Population	The Eurostat Dissemination Database, August 2020
Gross domestic product at current prices, in euro per capita	The Eurostat Dissemination Database, August 2020
Final Consumption of electricity, in Gigawatt-hour	The Eurostat Dissemination Database, August 2020
Total capacity and capacity by source of electricity production, main activity electricity producer only, in megawatt electric	The Eurostat Dissemination Database, August 2020
Imports, in thousand tonnes of oil equivalent Exports, in thousand tonnes of oil equivalent	The Eurostat Dissemination Database, August 2020

Table A2 Country weights for synthetic Poland (wind share as outcome variable)

Country	Weight	Country	Weight
Austria	0	Ireland	0
Belgium	0.012	Italy	0.096
Germany	0	Luxembourg	0
Denmark	0	Netherlands	0
Greece	0	Portugal	0
Spain	0	Sweden	0
Finland	0.559	United Kingdom	0.333
France	0		

Table A3. Pre-2013 predictor means for Poland, synthetic Poland and the average of the donor pool (wind share as an outcome variable)

Variable	Poland	Synthetic Poland	Donor Pool
Ln population	17.46	17.33	16.45
Ln GDP per capita	8.68	9.95	10.31
Ln Electr. Final consump. per capita	7.99	8.56	8.75
Ln capacity total	10.29	10.65	10
Ln capacity combustibles	10.2	10.18	9.24
Ln capacity hydro	7.7	8.69	7.8
Ln imports	10.39	11.41	10.7
Ln exports	9.85	9.57	9.24
Share of wind (2012) (%)	2.93	2.68	6.14
Share of wind (2010) (%)	1.06	1.41	3.85
Share of wind (2005) (%)	0.16	0.56	1.85

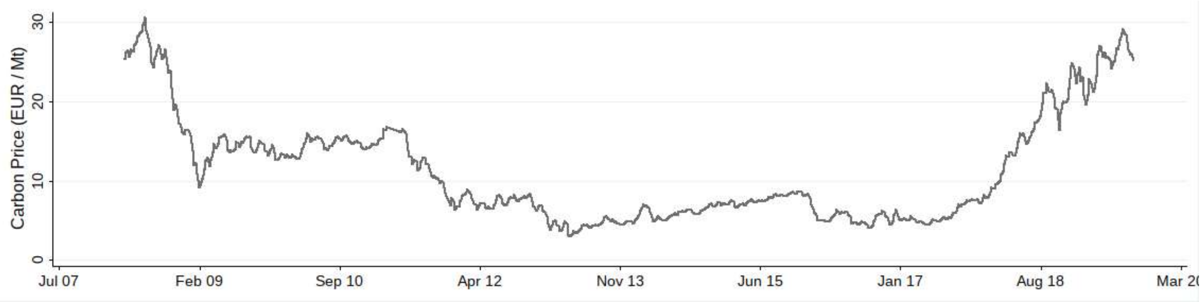

Fig. A1. Evolution of the carbon price over time (April 2008 to September 2019), in EUR per Megaton (Mt)

Data source: Sandbag Carbon Price Viewer (2019). Available at https://sandbag.org.uk/carbon-price-viewer/.