Coal's Last Breath: Examining Health Impacts in England's Coal's Phase Out

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Abstract

This study used a natural experiment to determine how a nation-wide coal phase out strategy affects air pollution and in-turn health outcomes (physical and mental health) in England. The introduction of the Carbon Tax policy in the United Kingdom in 2013, precipitated the closure of multiple coal plants, highlighting the imperative for further investigation into its implications. Using a Staggered Difference-in-Difference estimator, we show coal plant closures improve air quality and related health outcomes. In particular, we find coal plant closures reduces hospital admissions among respiratory patients, and asthma (among adults). Additionally, they reduce mortality among the most deprived under the age of 75 years, but not among the non-deprived population. Finally, we also document improvements on mortality for mental and behavioral diseases. This results, we show, are not driven by endogenous migration flows. These findings contribute to the literature on the health effects of pollution by focusing on the effects of removing, rather than adding, pollution sources that in this case result from more stringent climate policies.

Keywords: Coal-fired plants; Pollution; Physical health; Mental health

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1. Introduction

Coal-fired power plants have been an important energy-generation facility, which is the main catalyst for industrial revolution and economic development. However, more stringent climate policies –with higher carbon prices (where available), combined with lower prices in natural gas have made coal less competitive in electricity generation, leading many countries to actively phase-out coal plants. One of these countries is the United Kingdom, home of the first-ever coal powered plant in 1882 and the first major economy to completely phase out coal-fired plants from its energy mix (the last coal plant in UK closed in September 2024). This setting provides a unique opportunity to provide insights into the side effects of coal phase-out strategies in an advanced economy, in particular those related to its pollution and its health impacts. This paper exploits the last twenty years with coal plant closures all over England to analyze how derived reductions in pollution affected both on physical and mental health.

Coal in the UK has been traditionally used for a range of uses including industry, heating homes or railways. This historical high consumption of coal in the UK has led to various episodes of high pollution. The "Great Smog" of London in 1952 is one the most lethal examples that critically raised public concern and led to the Clean Air Act in 1956. However, since then coal's main use grew limited to the electricity generation. In its highest point in the year 1956 electricity accounted for 20% of its final use, consumption of coal was 221 million tonnes. By 1970's the coal consumption dropped to 120 million tonnes with electricity generation accounting for about 60%. By the 2000's coal use remained stable at 50 million tonnes, with 80% of it used for electricity generation. It is not until the emergence of more competitive gas plants in the 90's and the tightening of environmental and climate policies in in the 2010's when a major drop in coal use is observed. Regarding the latter, the introduction UK Carbon tax, motivated by the too low carbon prices in the European carbon market (EU ETS) and the binding reduction targets under Climate Change Act of 2008 (Leroutier, 2022) led to the closure of many plants emitting heavily.

The link between coal plants pollution and its health impacts is well documented in the literature. Emissions from coal-based power plants, including COx, NOx, SOx, particulate matter (PM) and other heavy metals, are associated with deteriorating health outcomes. When these emissions mix with rainwater, they cause acid rain, which not only leads to health issues, like skin cancer, nose irritations, asthma, headache, destabilisation of heartbeats but also impacts the food web. Additionally, chemical reactions between nitrogen dioxide and PM 2.5 leads to cardiac arrhythmias in adults, chronic obstructive pulmonary disease (COPD), asthma, and increase in mortality among infants (Munawer, 2018). These factors have contributed to an estimated 80,000 to 115,000 premature deaths and 20.5 million asthma cases only in India, costing the government approximately USD 3.2 to 4.6 billion (Guttikunda & Jawahar, 2014). Also, higher exposition to fossil fuel power plants as associated with increased mortality from COVID-19 (Tanaka, 2024).

On the other hand, the literature identifying positive effects that should emerge when the coal plant closes –i.e. whether the negative health impact remains long after or vanishes—is an empirical question less studied. Only few exceptions have identified positive (causal) effects resulting from particular plant closures. For instance, Komisarow and Pakthigian (2022) find three coal plant closures in Chicago resulted in lower absenteeism in elementary school, potentially mediated by reduction in the rate of emergency department visit. Yang and Chou (2018) find the closure of a coal plant in New Jersey reduced the probability of having a low-birth-weight baby in the area. Only three studies focus on a more general setting: Rivera et al. (2024) find the displacement of coal generation by large-scale solar power in Chile leads to a reduction in hospital admissions related to respiratory diseases. Lin and Jin (2024) look at the closures of highly emission intensive coal plants in twenty Chinese counties on a subjective health measure; the probability of reporting having been sick in the past four years. A study in Colorado found that proposed decommissioning of two coal-fired power plants led to two fewer premature deaths, fall in hospitalizations, and other morbidities, due to reduction in PM2.5 emissions (Martenies, Akherati, Jathar, & Magzamen, 2019). We contribute to this literature by focusing on nation-wide phase out scenario of an advanced economy from 2000 to 2020 and looking at a set of objective health measures.

Due to nuanced variations arising from timings of closure of coal plants, our identification strategy relies on staggered difference-in-differences methods (Callaway and Sant'ana, 2020). Our treated group consists of local authorities hosting a coal plant and the bordering local authorities. By including the latter, we assume spillovers are spread beyond the local authority and hence assume a more conservative approach. As a control group we use local authorities hosting a functional coal plant (not-yet-treated), although we also compare our treated group to other local authorities without coal plants. Parallel trends assumption is shown to be plausible by means of event studies.

The results show the closure of coal plants significantly improves air quality, as nitrogen dioxide decreases by 4.42 micrograms, on average (or a reduction of 15.2%). This led, we show to a significant reduction in the hospital admissions among respiratory and asthma patients, as on average, it decreased by 4.1% and 10.7% respectively. We look at mortality rates for most and least income deprived people living in the treated and the control group in the local authorities: Mortality of people under 75 who are most deprived reduced by 3.56%, on average, due to the closure of coal plants in the treated local authorities while no significant reductions were found for least deprived ones. Lastly, we find mortality due to mental and behavioral diseases also declined by 5.45%, on average, in the local authorities hosting or neighboring a closing coal plant. These results, we show, are not driven by endogenous migration flows: closure of plants did not lead to any significant population changes in the treated local authorities, leaving the improvement in the air quality as the main mechanism.

These results are directly relevant for policy debates occurring in last Climate Conferences on coal phase-out international commitments. Many countries still rely heavily on coal and some are even increasing their coal capacities. Although most of the European countries have already announced coal phase out plans, coal dependency is highly heterogenous and many plan to do so later than 2030, key to be in line with UN Paris Climate Agreement (European Commission, 2019). Also, we contribute to this growing literature by covering a wider set of health indicators, including mortality rates, hospital admissions according to different diseases and mental health indicators. Finally, so far coal plant closures are, in part, the aftermath of implemented national climate policies – carbon pricing in the UK— this paper also contributes on documenting co-benefits of national climate policies on present generations, which can be key to increase public acceptance of climate policies in general. In this regard, our results also suggest local benefits of shifting from fuel base power generation to more renewable and less polluting source of energy.

The paper is as follows: section 2 explains a detailed review of the previous work on how coal plants pollution can impact health, and reviews the current state of art on coal phase out globally and in detail for the UK. Section 3 mentions the data collection and the methodology used. Section 4 describes the results of our analyses. Section 5 discusses the robustness checks conducted to validate our findings. Section 6 offers an in-depth discussion of the results, and Section 7 concludes the paper, summarizing the key insights and implications of the study.

2. Background

2.1 Health Impacts of Pollution Exposure

The industrialization led to the expansion of coal power plants in the Britain, which provided an unprecedented rate of growth and left some negative effects behind. The coal-fired power plants, a crucial source of energy in industrialization period, are responsible for the air pollution (Kopas, et al., 2020). Overall, combustion of fossil fuels has led to a rise in 66% deaths due to modern pollution in the last couple of decades (Fuller, et al., 2022). According to data by the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD), 2015, evaluated that 16% of the deaths (or 9 million deaths) worldwide. A study of the impact of outdoor air pollution on the mortality in China revealed that levels of air pollution and mortality related to cardiopulmonary diseases and lung cancer are significantly related (Caoa, et al., 2011). Various studies have indicated the negative impact of air pollution on the premature mortality, and it is estimated that it could increase by two times by 2050 at the global level if emissions remain at the same level (Lelieveld, Evans, Fnais, Giannadaki, & Pozzer, 2015).

In particular, coal-fired power plants release toxins and harmful air pollutants in the form of fine and ultrafine particles, like PM2.5, mercury, sulphur dioxide, carbon monoxide and other greenhouse gases (Finkelman, Wolfe, & Hendryx, 2021; Fuller, et al., 2022). People who are exposed to ambient air pollution, may suffer from respiratory issues because ultrafine particles, like PM2.5 can enter deeply in the lungs and do severe harm to the alveolar wall (Xing, Xu, Shi, & Lian, 2016). There are studies related to PM10 pollutant which is significantly related to the morbidity and mortality (Anderson, Thundiyil, & Stolbach, 2012; Chen, et al., 2012), with its impact varying with socio-demographic factors (Chen, et al., 2012). Nitrogen oxides (NOx = NO + NO2) are also hugely relevant in coal plant emissions. Coal plants account for 80% of global NOx emissions (Oberschelp et al.,2019) and satellite observations confirm NOx emission reach beyond the immediate vicinity of the installations (Tang et al., 2024). Exposure to NOx emissions have been found to be associated with several respiratory and cardiac diseases (Munawer 2018, Schlenker and Walker, 2016).

Beyond physical health impacts, pollution exposure is increasingly being related to mental health condtions. Emerging evidence suggested that the air pollution affects the brain aging (Block & Calderón-Garcidueñas, 2009; Zhang, Chen, & Zhang, 2018), as ultra-fine particulate matter enters the brain (Block & Calderón-Garcidueñas, 2009), and leads to psychotic illnesses like schizophrenia (Antonsen, et al., 2020), a disorder which affect thinking and behaviour. It implies that the increased levels of pollution worsen the mental health, leading to depression, anxiety, suicides, and other mental health issues (Lawrance, Thompson, Fontana, & Jennings, 2021). In addition to this, studies indicated that ambient air pollution, especially PM emissions, lead to changes in metabolism and higher stress (Li, et al., 2017), disproportionally higher among older men in specific cold months (Mehta, et al., 2015). On the other hand, short-run study on clean indoor air leads to reduction in stress hormones (Li, et al., 2017). A study on neurobehavior problems in children due to the impact of living in vicinity (within 10 miles) of the coal power plants finds that the proximity to coal plants is significantly related to the neurobehavioral problems like social problems, affective problems, and anxiety problems (Zhang, et al., 2021).

All in all, specialized literature is plenty of evidence showing both that pollution has detrimental effects on health and that coal plants are a source of local pollution. The extent to which these effects vanish whenever coal plants stop functioning permanently remains an empirical question.

2.2 Coal phase out

Coal combustion is still a major contributor to greenhouse gas emissions, accounting for approximately 70% increase in 2023 of global CO2 emissions from energy combustion. China and India increased substantially their emissions from coal combustion in 2023, only partially offset by the decline of the EU and US jointly with other advanced economies (IEA, 2023). Against this backdrop, the annual Conference of the Parties (COP) under the United Nations Framework Convention on Climate Change (UNFCCC) have played a significant role in framing the coal phase-out debate. However, differing levels of economic dependency on coal, political pressures from domestic industries, and concerns about energy security have prevented agreements on coal phase out from going beyond advanced economies. Economic factors, such as declining costs of renewable energy and, when implemented, increasing induced costs from climate policies make coal use less competitive against its alternatives, mainly natural gas, facilitating transitions away from coal (Gugler et al., 2021). For developing economies, in contrast, coal use remains a critical source to ensure economic growth and energy access. Accordingly, at COP26 in Glasgow, countries committed to "phasing down" rather than "phasing out" coal, reflecting compromises between ambitious climate goals and political realities.

In 2022, coal supplied 36% of the global electricity generation. To meet Paris Agreements, this must drop to 4% in 2030 and 0% by 2040. Most European countries have already announced their plans to phase out coal, with UK showing the fastest coal power reduction followed by Greece, Denmark Spain, Portugal, Romania and Germany. Out of Europe, US, Israel and Chile have also shown outstanding and fast coal use reductions in the last years. All of them, more than halved their coal share in electricity generation over the last decade (WRI, 2023). On the other hand, countries like China, Indonesia, India, South Africa, Poland or Turkey keep relying heavily on coal use to meet their electricity demand and do not contemplate any phase out strategy in the near future.

The case of UK's phase out is the aftermath of two separate drops in the coal use. The first one occurred in the 90's as a result of new development of cheap and abundant gas in the North Sea. The share of coal use in electricity generation moved from above 60% to below 30% in just ten years. The second drop occurs in 2013, when coal share went from 36% until below 2% in 2023. In this case, the main drivers were two environmental policies. First, the new EU legislation targeting pollution from large fossil fuel plants made coal plants either to upgrade infrastructures or close (many had to close). Second, the UK introduced the Carbon Price Floor destined to compensate the low carbon prices from the European carbon market (EU ETS). Altogether drove cost of coal power up, making gas and renewables more competitive. Our research will mainly capture this second drop.

Figure 1 shows the closure of coal plants in our sample, covering England stations from 2000 to 2022. In the year 2003, only 2 coal plants were closed out of 17 operating coal power plants taken for our study. The High Marnham power station (2003), the Drakelow power station (2003), and then the Wilton Cogen power station (2007), these coal plants were closed in the early 2000s. The Longannet Power Plant, the Ferrybridge C Power Plant, and the Rugeley Power Plant; the three largest coal plants in the UK were shut down in the year 2016 (Evans, 2016). The Eggborough Power Plant in 2018 (EP Power Europe) and Fiddlers Ferry Power Plant in 2020 (SSE Thermal) were closed. The dependence of energy generation has been changed from coal to other sources like wind energy, solar energy, hydro energy, nuclear energy, and gas (Evans, 2023). By the year 2022, 16 coal power plants have been closed, and only one coal-fired power plant is operating in England by the end of our sample, which is Ratcliffe power station.

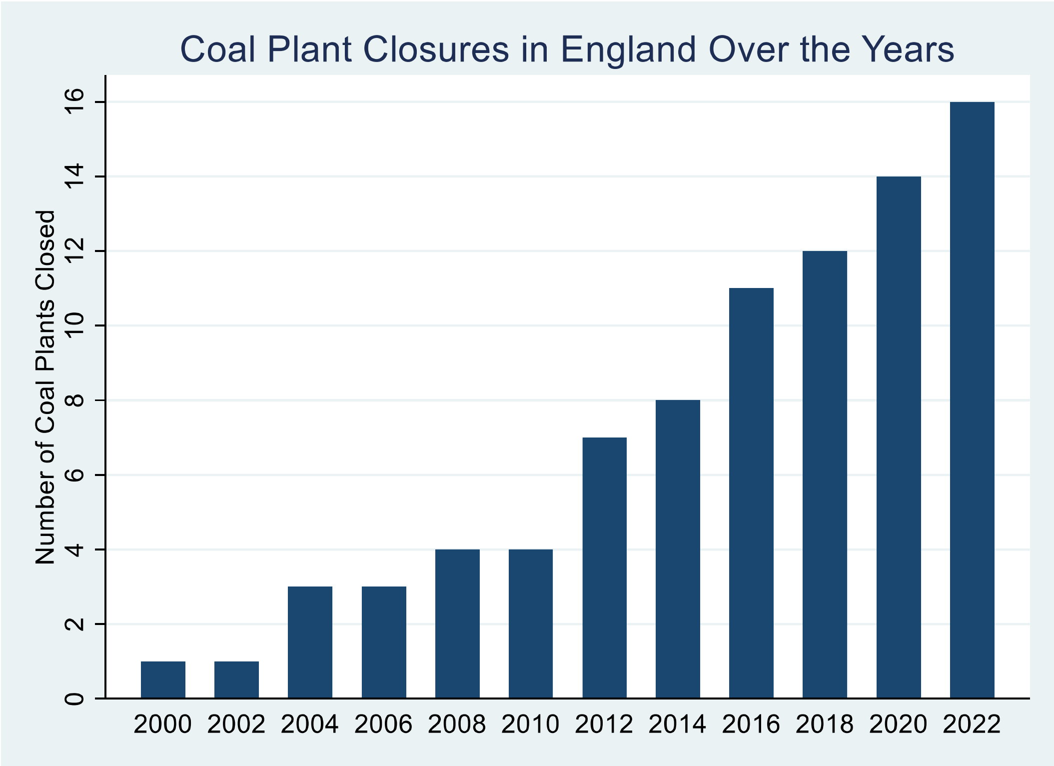

Figure 1. Coal Plants Closure in England over the years. Data Source: Global Energy Monitor

3. Methodology and Dataset

3.1. Identification Strategy

To find out the relationship between coal plant closures and its impact on the health outcomes, we will rely on a difference-in-differences strategy at the English local authority level.

First of all, a treated group and a control group have to be identified. The treatment variable defines the control group as zero when the plant is operating (coal plants have not been closed) and all their neighboring local authorities (by border). And the treated group as one when all the units are closed of a particular plant[4], and all their neighboring local authorities (by border). The assumption here is that a coal plant pollution does not only affect the hosting local authority but also bordering local authorities. This empirical decision is therefore conservative one. Figure 2 depicts the coal plants closure in the year 2000 versus the closure in the year 2022. In the year 2000, one coal plant was closed (but not all the units were closed in the local authority, that is why in fig2, it is shown in red color. However, by the year 2022 all except 1 were closed (the time-period which we are estimating in our analysis).

[4] Most of the coal power plants have more than one unit of the same plant. Moreover, in some local authorities, there are more than one coal power plant.

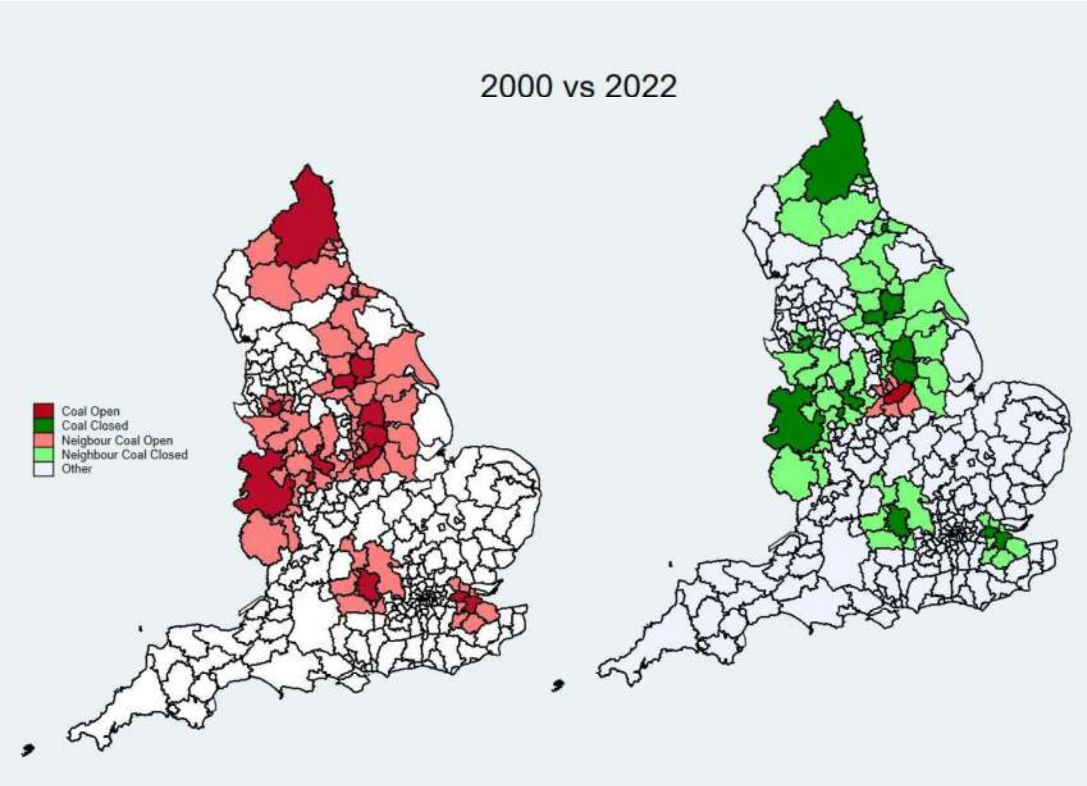

Figure2. Closing of coal plants in the local authorities in England in the year 2000 v/s 2022. Data source: Global Energy Monitor

There were some neighboring local authorities, which were sharing border with the local authority which closed the coal plant and which did not. By simple logic, this research has considered it to be a part of the local authority which did not close the coal plant (or the control group). This is due to the reason that the local authority where the plant is open is still emitting pollution, meaning there will be still some pollution from coal-fired power plants in the neighboring local authorities.

Since, coal-fired power plants tend to close at different time, the research will exploit the exogenous variation from the coal plant closures through a staggered difference-in-difference approach. The staggered difference-in-difference will allow to study the units (local authorities) entering the treatment group (closure of coal plant) at different points in time, which would not be estimated by the canonical difference-in-difference technique. The methodology developed by Callaway & Sant'Anna (2020), and is used for estimating the model with multiple time periods, will be used here.

The components of staggered difference in difference are

$$ATT\ (g,t) = \mathbb{E}\ [Y_{i,t}(g) - Y_{i,t}\ (g')/G_i\ = g] \quad (1)$$

where, g = group, t = time period, Y= Variable of Health Outcome

In the cases where the local authorities do not have coal plants, it would be a never treated case, and denoted by $g' = \infty$ meaning that

The cases in which the local authorities have coal plants but have different closure periods and not yet closed will be a not yet treated case, denoted by $g' > t$.

Here, not yet treated cases, will be applied, so that treatment and control groups are more similar also in terms of unobservable.

The estimated model would be:

$$H_{i,t} = \delta_t + \alpha_g + \beta_1\, DID + \beta_3 X + \varepsilon_{i,t} \quad (2)$$

Here, $H_{i,t}$ is the health outcome, δ_t is the time fixed effect, α_g is the group fixed effect, D_iD = Treatment X Post Treatment Period, which implies, coal plant in the local authority (and its neighboring) and it is closed.
$\beta_1 = parameter\ of\ interest$,
X = Covariates including income deprivation, population, share of 65 people.

The main assumptions of the canonical Difference-in-Differences model are parallel trends assumption, no anticipation, and Stable unit treatment value assumption (SUTVA). The parallel trend assumption posits that prior to the implementation of a treatment, both the treatment group and the control group should exhibit similar trends. This suggests that any differences observed between the two groups after the treatment can be attributed to the treatment itself rather than pre-existing disparities. In the context of an event study, adherence to the parallel trend assumption entails that estimates preceding the treatment year are statistically insignificant or demonstrate negligible effects, reaffirming the absence of differential effects prior to the treatment.

No anticipation assumption refers that treatment path is not known a priori. Lastly, SUTVA assumption means that the control group should not be affected by the treatment. Since, we estimate our model by Staggered Difference-in Difference by Callaway and Sant'ana, besides of these above assumptions, we also need to have conditional parallel trends assumptions on a "Never-Treated" or a "Not-Yet-Treated" group (Callaway & Sant'Anna, 2020). It implies this assumption holds after controlling for covariates. Since, our treatment is closure of coal plants in different years, we have used a "Not-Yet-Treated" group. Lastly, there should be a positive proportion of population starts from period g (Callaway & Sant'Anna, 2020).

Further, we use event study model to estimate the length of exposure of treatment effect of closure of coal plants on the emissions, and the health outcomes.

$$H_{i.t} = Closure_{i,t-j} \sum_{j\in(-m,\ldots0,\ldots,n)} \gamma_j + \alpha_i + \delta_t + \beta X_{i,t} + \varepsilon_{i,t} \quad (3)$$

Here, $Hi.t$ is the health variable, which is our outcome variable. Closure is the coal plant closure in the local authority and its neighboring.

$\sum_{j\in(-m,\ldots0,\ldots,n)} \gamma_j$ is the time-period when the closure is happening. α_i and δ_t are the panel fixed effects. $X_{i,t}$ is the control variables, and $\varepsilon_{i,t}$ is the error term.

Besides of plausibility of parallel trends, the event study estimates are useful to capture the long-term effects of the coal plant closures on the level of emissions and health outcomes, key for our research question. Once a coal plant stops emitting some health outcomes may take longer than other in reacting. Some health outcomes like mortality do not change rapidly in few years. Exposition can have longer impact.

We also did the Placebo tests to check for the robustness of our results. We have used Placebo treatment timing test. In which a placebo treatment is created which is 2 years before the closure of the coal plants. If the first plant closes in the year 2003 then in the placebo test it is assumed that it closed in 2001, and so on. Then, we analyse the emissions and health outcomes in the similar way to that of the original treatment. We used the Callaway and Sant'ana difference-in-difference causal technique, with event study approach. This method will tell if the results we get earlier were robust or not. If these variables turn out to be significant it means that our results are not robust and there is something going on with the variables which cannot be explained by the models and the improvement in the emissions and health outcomes are not truly determined by the coal plant closures. However, if the results of the placebo tests are insignificant it means our results are robust and the reduction in emissions and improvement in the health outcomes can be explained by coal plant closures through reduction in emissions.

Finally, we have also included all the local authorities, irrespective of the presence of coal plants. We used the same causal inference technique of Callaway and Sant'ana and event study approach, to test for external validity. If the significant results are significant, then it means that the results are validating and robust.

3.2. Data

We compiled a panel dataset of all the English local authorities from 2000 to 2022. A local authority in the England oversees the council services. They are government bodies responsible for managing public services, like education, waste management, housing, local taxation, and facilities within specific geographic areas, such as cities, towns, and counties (Government of the UK, 2016).

As of 2021, there are 317 local authorities in England, which consists of county councils (21), district councils (164), unitary authorities (62 and the Isles of Sicily), metropolitan districts (36), and London boroughs (32 and the City of London) (Government of the UK, 2016). Out of 317 local authorities, 14 local authorities have or previously had a coal power plant. So, we have taken those 14 local authorities and their neighboring local authorities are 64. Therefore, we have taken 78 local authorities for our analysis. This will determine our treated and control groups. Treated local authorities will be those with coal plant being closed during the period of analysis, and their neighboring local authority. Control groups are those local authorities with coal plant still operating, and their neighboring local authorities.

The dataset comprises data from four different data sources at the local authority level from coal plants in England detailing its closures, the health outcomes in these local authorities, and emissions from different pollutants.

The data on the closure of coal power plant in England has been collected from the Global Energy Monitor, a non-governmental organization from San Francisco, which shares information and data on clean energy and fossil fuels at the global level. There are 30 coal power plants in the UK, out of which 20 are in England, 2 are in Wales, 2 are in Northern Ireland, 6 are in Scotland. Out of 20, 17 coal power plants are either operating or retired, and 3 were cancelled before its operations (so those are not included in our study). Since, our analysis is focusing on England's coal plants closure, we have incorporated 17 coal power plants in the 14 local authorities of England (Global Energy Monitor, 2023). Figure 1 shows the map of the local authorities having a coal plant, which are either operating or retired over the period 2000-2022, in England. They have been mapped to their respective local authority from their location. The dataset contains the number of units of each coal plants (up to 6 units per plant), the local authority to which they belong, the start and the retired year.

The health data of England has been collected from the Nomis (Official Census and Labour Market Statistics of the UK), and Fingertips (Office for Health Improvement and Disparities) for the period 2000 to 2020. This includes emergency hospital admissions for asthma for children and adults, emergency hospital admissions for respiratory issues, and emergency admissions for children with lower tract infections (Fingertips). Some variables related to mortality are also collected, mortality due to mental and behavioral disorders, mortality due to diseases of respiratory system, mortality due to asthma, mortality under 75 most deprived and least deprived, mortality under 75, suicide rate among males, and suicide rates among females.

Finally for emissions data, we collected emissions data from UK-AIR (Air Information Resource), using the R package 'openair' (Carslaw, & Ropkins, 2012). The variables related to emissions include Nitrogen Dioxide (NO2), Nitric Oxide (NO), and PM10.

After collecting all the data; coal plant closures, health, and the emissions data, it was merged at the local authority level and a panel data is formed from the year 2000 to 2022. One limitation of this study is the presence of missing data for some years for health variables which led to unbalanced panel data and for less observations for some variables. This could introduce potential biases or limitations in the analysis, as the absence of data could impact the accuracy and reliability of the findings.

Table 1 shows the main descriptive statistics of the important variables studied in this research, catering to only those local authorities having a coal plant or is a neighbor. A panel for 8257 observations from 78 local authorities from the year 2000-2022 is constructed.

Table 1, shows that on average, nitric oxide, nitrogen dioxide, and PM10 are 31.83 µg m-3, 37.077 µg m-3, and 21.25 µg m-3 respectively, in the 78 local authorities for the year 2000-2022. The average population of England for the year 2001-2020 is 171218. On average the emergency admissions for respiratory diseases, children with lower tract infections, asthma (under 19 years), and asthma (aged 19 years and above) are 1344.15 people admitted, 379.60 people admitted, 166.33 children admitted, and 81.57 people admitted, respectively for the year 2013-2020. The mean of mortality due to respiratory and mortality over 75 years are 426.96 deaths and 2268.54 deaths respectively, for the year 2013-2021. On average, the unemployment rate is 5.6% in England for the period 2004 to 2022. The share of 65 and above people in England are 15%, on average, for the period 2001 to 2020.

Table 1. Descriptive statistics for the local authorities having a coal plant and its neighbor local authorities

Variable	Year	Observations	Mean	Std. dev.	Min	Max
Active Coal Plant nearby	2000-2022	184	.102	.303	0	1
Closed a Coal Plant	2000-2022	1,610	.897	.303	0	1
Emissions						
Nitric Oxide (NO)	2000-2022	979	31.832	24.621	1.185	167.108
Nitrogen Dioxide (NO2)	2013-2022	979	37.077	16.190	8.059	123.094
Particulate Matter 10 (PM10)	2007-2022	852	21.252	5.113	10.271	40.188
Population	2001-2020	6,180	171218.1	115549.9	2140	1141816
Health Outcomes						
Emergency Hospital Admissions for Respiratory Diseases	2013-2020	2,498	1344.157	380.632	511.07	2915.92
Emergency Admissions for Children with lower tract infections	2013-2020	2,509	379.603	181.097	19.7	1058
Hospital admissions for asthma (under 19 years)	2013-2020	2,496	166.339	73.317	17.47	537.97
Emergency hospital admissions for asthma in adults (aged 19 years and over)	2013-2020	2,498	81.574	25.943	28.27	242.72
Mortality Due to Respiratory Diseases	2013-2021	1,368	426.966	364.962	0	2278
Under 75 Mortality	2001-2016	5,186	364.665	76.876	201.038	705.769
Under 75 Mortality Least Deprived	2002-2014	4,212	263.793	47.772	125.479	494.618
Under 75 Mortality Most Deprived	2002-2014	4,212	516.481	125.125	219.939	995.414
Mortality due to Asthma	2006-2020	4,225	2.305	.725	0.673	9.282

Mortality Over 75 years	2013-2021	1,368	2268.545	2035.518	5	12136
Mortality Due to Diseases of Mental and Behavioral	2013-2021	1,354	283.397	262.111	0	1618
Suicide Rate Male	2001-2019	5,518	15.709	4.246	5.310	38.628
Suicide Rate Female	2001-2019	2,531	5.837	2.030	1.722	16.100
IMD Average (Income Deprivation)	2000-2020	6,828	19.763	9.211	4.132	61.341
Unemployment Rate	2004-2022	5,209	5.641	2.600	0.9	22.3
Share of age-65	2001-2020	2,560	0.155	0.038	0.060	0.294
Net Migration	2010-2019	3450	83.6182	5228.996	-106608	34019

4. Results

4.1. Coal Plant closures and Emissions

We first estimate the impact of coal plant closures on the emissions. We have included Nitrogen Dioxide (NO2), Nitric Oxide (NO), and Particulate Matter 10 (PM 10) for emissions. Given data constraints, we chose to use a control group consisting of all the local authorities even without coal plants for this case. We will thoroughly address potential concerns through comprehensive robustness checks.

The covariates included in this model are population, deprivation score (measured by IMD Average), and share of 65 people. These variables could be having some relationship with the outcome variable (to address to endogeneity problem) and to have conditional parallel trends, we have included these covariates in the study.

First, in table 2, we estimated the closure of coal plants on nitrogen dioxide (NO2) which, is inversely related and is significant. The overall ATT shows that the levels of nitrogen dioxide have reduced by 4.429 micrograms, on average, in each cubic meter of air (µg m-3) in the focused local authority and its neighboring compared to the local authorities and its neighboring which did not have the coal plants. Then, we analyzed the levels of nitric oxide and coal plant closures. However, the ATT for all groups across all periods is not significant. Lastly, we estimate closures of coal plants on the levels of PM10 thereafter, which is negatively related, but not significant.

Figure 3 depicts the potential parallel trends assumption. Figure 4 displays the event study approach at the yearly level. In the figure 4, nitrogen dioxide starts to fall after the 0 period (or period after the coal plants closure), then it starts to increase in the 5th period. Nitric Oxides also decrease initially till 5th period and then it starts to increase. Particulate Matter (PM10) follows a similar pattern, as it starts to fall till 3rd period then it starts to increase.

Table 2. Emissions and coal-fired power plants closure

	Nitrogen Dioxide (NO2)	Nitric Oxide (NO)	PM10
Differences in Differences Model			
Closures X Post	-4.429*** (2.132)	-2.235 (2.889)	-1.252 (0.986)
Event Study Model			
Year -13	-3.785** (1.643)	-5.327** (2.171)	0.390 (0.398)
Year -12			0.397 (0.345)
Year -11	-1.113 (1.030)	-4.945*** (1.447)	0.366 (0.612)
Year -10	-2.333 (3.864)	3.619 (6.900)	-1.193* (0.617)

Year -9	3.915 (2.682)	-3.843 (3.560)	-0.572 (0.542)
Year -8	0.328 (1.305)	-1.947 (1.412)	-0.213 (0.707)
Year -7	1.454 (5.945)	-3.288 (4.019)	-0.505 (0.956)
Year -6	-5.953 (3.848)	-0.918 (4.241)	-1.141 (1.598)
Year -5	1.809 (2.200)	-0.634 (3.591)	-0.328 (0.758)
Year -4	1.419 (3.001)	-0.773 (2.533)	0.547 (0.549)
Year -3	-0.679 (2.536)	1.727 (4.960)	1.714** (0.795)
Year -2	-1.403 (1.916)	-0.151 (2.722)	-0.652 (1.286)
Year -1	2.173 (1.649)	2.464 (3.185)	0.734 (1.061)
Year 0	0.359 (3.093)	5.500* (3.201)	-0.260 (0.916)
Year 1	-4.760*** (1.460)	-6.385*** (2.391)	-0.854 (3.083)
Year 2	-5.478*** (1.240)	-5.363*** (1.500)	-3.333 (2.945)
Year 3	-10.547*** (2.434)	-11.668*** (1.281)	-2.662** (1.056)
Year 4	-12.056*** (2.454)	-7.008 (6.769)	-2.042 (1.626)
Year 5	-5.679*** (1.361)	-9.853*** (2.652)	-0.235 (0.351)
Year 6	-5.614*** (2.026)	-4.927 (3.335)	0.101 (0.524)
Year 7	-0.479 (2.700)	4.620 (4.104)	-2.804*** (0.550)
Observations	333	410	374
Controls	Yes	Yes	Yes

*Note: This table displays result of staggered difference-in-difference model and event study. The sample is defined as emissions in the local authority and coal plant closures (for the period 2000-2022) in England. Parentheses contain the se. Significance Levels: * = 10%, ** = 5%, *** = 1%*

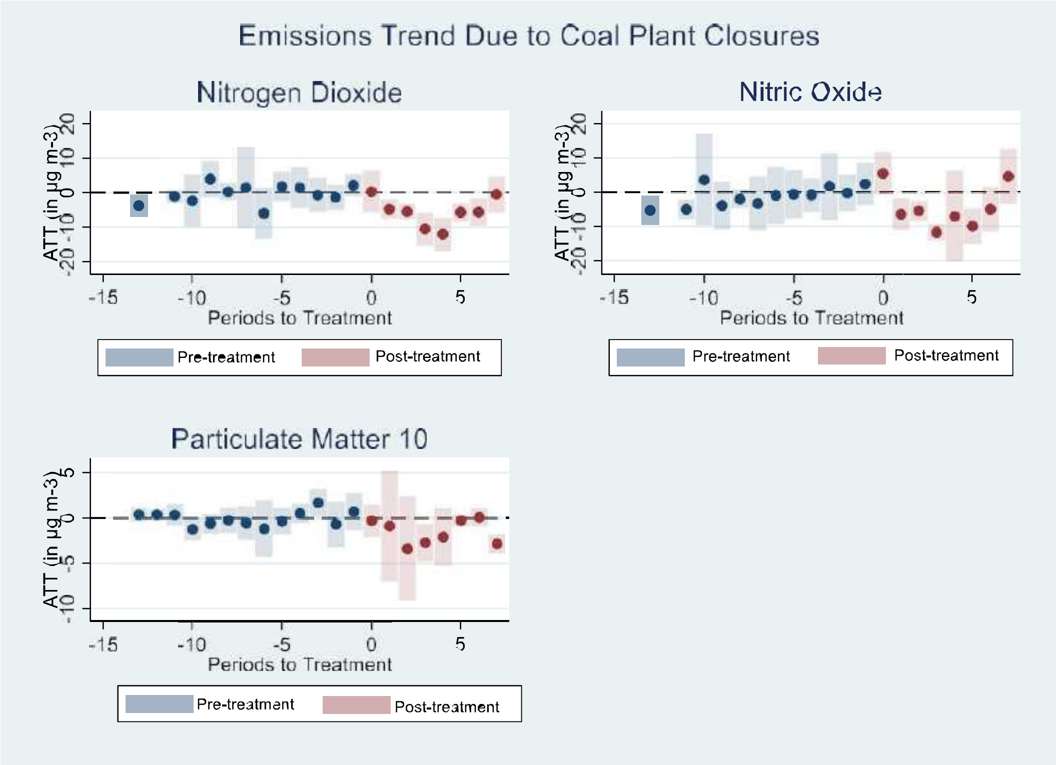

Figure 3. Event study of emissions due to closure of coal-fired power plants

4.2. Coal Plant Closures and Health Outcomes

4.2.1 Hospital Admissions

The first health outcome analyzed is emergency hospital admissions related to respiratory complications, as a measure of short-term health impact. For this, we have taken emergency hospital admissions for respiratory diseases, emergency admissions for children with lower tract infections, emergency hospital admissions for asthma (aged 19 years and older), and emergency hospital admissions for asthma (aged under 19), all in logarithms. The covariates used in the regression are population and deprivation score (IMD scores).

Table 3 reports these results, first, with the overall ATT and then, by year-effect. For these variables we have less years, we have 8 periods before the treatment and 5 periods after the treatment.

Figure 4 depicts the potential parallel trends assumption. It illustrates the hospital admissions for respiratory diseases and for asthma (aged 19 and above) started to fall and has a decreasing trend after the treatment (closure of the coal plants) has taken place. Moreover, hospital admissions for children with lower tract infections has first decreased then it increased till 4th period and it again decreased in the 5th period. However, the figure 4 shows that hospital admission for asthma (aged under 19) has an increasing trend.

The results for emergency hospital admissions for respiratory diseases indicate a negative and a significant effect when the coal plant closes in the local authorities and its neighboring. It implies that there has been a reduction in emergency hospital admissions for respiratory diseases by 4.12%, on average. Moreover, there has been a fall of 10.79% (on average) for the emergency hospital admissions for asthma among adults in the local authorities closing the coal plants and its neighboring, compared to those local authorities have not closed the coal plants (and its neighbor). Further, emergency admissions for children with lower tract infections is significant in the 5th period after the coal closures, implying that due to closures of coal plants in those local authorities and its neighboring encountered, on average, 28.8% less patients of lower tract infections among children than those local authorities which did not close the coal plants (and its neighbor). The variable hospital admissions for asthma among children is not significant.

Table 3. Hospital Admissions and Coal Plants Closure

	Emergency Hospital Admissions for Respiratory Diseases	**Emergency Admissions for Children with lower tract infections)**	**Hospital Admissions for Asthma (aged 19 years and over)**	**Hospital Admissions for Asthma (aged under 19)**
Difference-in-Difference Model				
Closures X Post	-0.041** (0.016)	-0.046 (0.056)	-0.107*** (0.032)	0.044 (0.057)
Event Study				
Year -8	-0.036 (0.037)	0.144 (0.106)	-0.049 (0.095)	0.009 (0.048)
Year -7	-0.013 (0.032)	-0.151 (0.192)	0.144* (0.076)	-0.105 (0.135)
Year -6	0.022 (0.026)	0.074 (0.062)	0.018 (0.048)	-0.057 (0.056)
Year -5	-0.031 (0.024)	-0.102 (0.093)	-0.115*** (0.040)	0.072 (0.061)
Year -4	0.074* (0.040)	-0.018 (0.065)	0.112* (0.065)	-0.131** (0.051)
Year -3	-0.090** (0.041)	-0.011 (0.088)	-0.151*** (0.049)	-0.006 (0.045)
Year -2	0.025 (0.021)	-0.0003 (0.058)	0.089** (0.041)	-0.035 (0.055)
Year -1	0.003 (0.016)	0.095** (0.048)	0.017 (0.038)	0.011 (0.041)
Year 0	-0.020 (0.021)	-0.028 (0.051)	-0.095*** (0.033)	0.030 (0.050)
Year 1	-0.031** (0.014)	-0.030 (0.064)	-0.138*** (0.045)	0.040 (0.053)
Year 2	-0.061 (0.038)	-0.124 (0.125)	-0.099* (0.050)	-0.051 (0.109)
Year 3	-0.058** (0.023)	-0.061 (0.083)	-0.141** (0.055)	0.076 (0.1003)
Year 4	-0.035 (0.022)	0.138 (0.096)	-0.079 (0.051)	0.095 (0.101)
Year 5	-0.092*** (0.035)	-0.288*** (0.111)	-0.074 (0.074)	0.233*** (0.090)
Obs.	336	333	336	336
Controls	Yes	Yes	Yes	Yes

*Note: This table displays result of staggered difference-in-difference model and event study. The sample is defined as hospital admissions in the local authority for the period 2013-2020 and coal plant closure from 2000-2022 in England. Parentheses contain the se. Significance Levels: * = 10%, ** = 5%, *** = 1%*

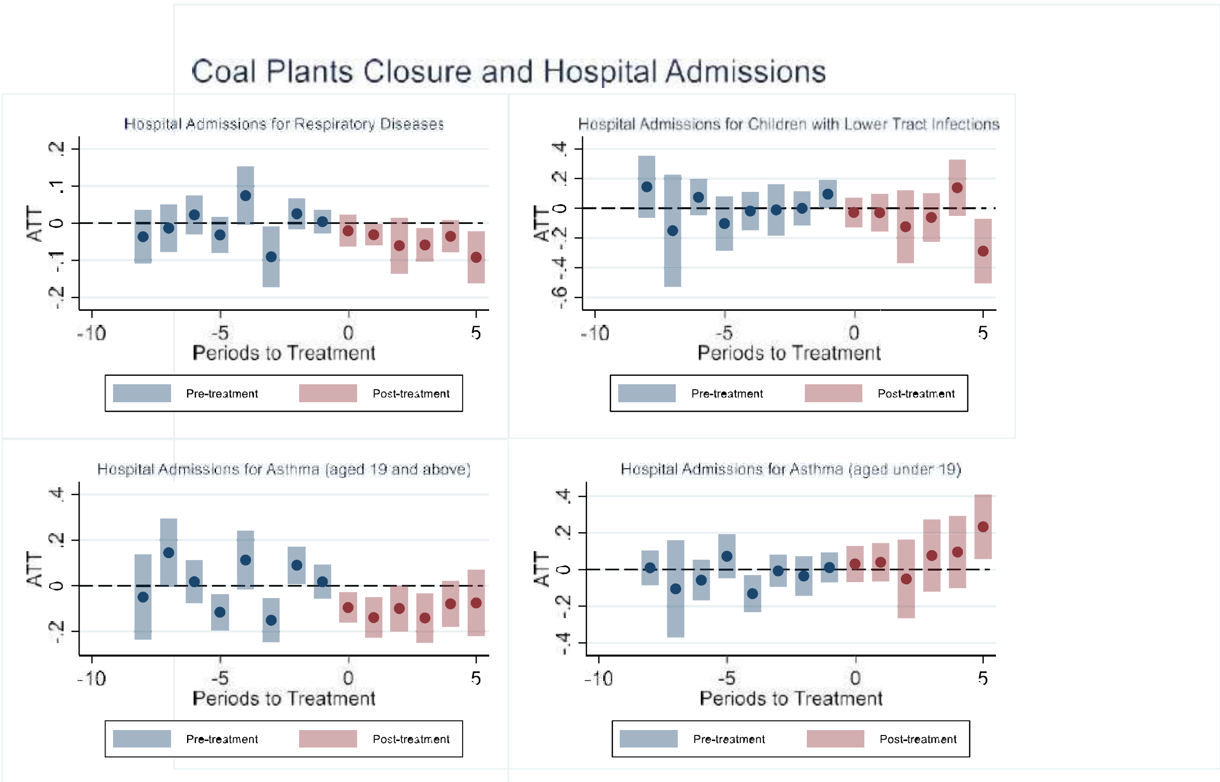

Figure 4. Event study of hospital admissions due to closure of coal-fired power plants

4.2.2. Coal Plant Closures and Mortality

We are interested in finding out the long-term phenomenon which is mortality, as it takes some time to prevent mortality. To measure the impact of closure of coal plants on mortality, we have used Mortality under 75, mortality under 75 for most deprived, mortality under 75 for least deprived, mortality due to asthma, mortality due to respiratory diseases, all in logarithms. The covariates used in the regression are population and deprivation score (IMD score), except for mortality under 75 for most deprived and least deprived, where only population as the covariate has been used (because it automatically controls for the deprivation score), and no covariate has been taken for mortality over 75.

Table 4 present the results of mortality due to different causes, with each variable encompassing varying durations for pre-treatment and post-treatment periods. Specifically, mortality among people under 75 years of age includes 20 years before the treatment and 13 years after the treatment. Mortality among the most deprived and least deprived under 75 years of age includes 19 years before the treatment and 11 years after the treatment. Mortality due to asthma includes 15 years before the treatment and 13 years after the treatment. Mortality due to respiratory diseases includes 8 years before the treatment and 5 years after the treatment. Lastly, mortality among individuals above 75 years of age includes 8 years before the treatment and 6 years after the treatment.

Our findings show that mortality for people aged under 75 who are most deprived has reduced. Closure of coal plants lead to, on average, 3.56% less deaths for under 75 most deprived people in the local authorities which has closed the coal plants and their neighboring local authorities, compared to local authorities and its neighbor where the coal plant has not been closed. Mortality for under 75 people who are least deprived, does not have any impact. It could be the most deprived people are more prone to air pollution, and might be living near the coal-fired plants.

Mortality due to asthma and respiratory diseases are significant only after certain time has passed. Since, it is a long-term event, mortality due to Asthma has become negative and significant after the 10th period and there is on average a 30% fall in the mortality after the coal plant closures. Furthermore, mortality due to respiratory diseases has become negative in the 4th period, it is around 0.6% after the coal plant closures, however it is not significant.

Mortality for the people over the age of 75 is not significant, however, it is negative when coal plant closes, it implies that the mortality is due to aging or natural factors among them. It remains the same throughout.

Figure 5 depicts the potential parallel trends assumption. The figure illustrates that mortality under 75 is not significantly negative after the closure of the coal plants. Mortality under 75 among the most deprived people starts to decline after the 4th period after the closure of coal power plants and mortality due to asthma starts to decline significantly after the 10th period after the closure of coal plants. Mortality under 75 for least deprived did not decline significantly after the closure of the coal plants. Mortality due to respiratory diseases decreases after 4th year, however it is not significant. Mortality aged over 75 starts to decline after the 4th period, however it is not significant.

Table 4. Mortality and Coal Plants Closure

	Under 75 Mortality	**Under 75 Most Deprived**	**Under 75 Least Deprived**	**Mortality due to Asthma**	**Mortality Due to Respiratory Diseases**	**Mortality Over 75 years**
Differences in Differences Model						
Closures X Post	0.004 (0.008)	-0.035** (0.016)	0.022 (0.017)	0.024 (0.044)	0.0002 (0.025)	-0.007 (0.013)
Event Study						
Year -20	0.021 (0.026)					
Year -19	-0.003 (0.019)	-0.059*** (0.019)	-0.018 (0.019)			
Year -18	-0.0003 (0.009)	0.001 (0.025)	-0.008 (0.021)			
Year -17	-0.006 (0.018)	0.018 (0.016)	-0.030 (0.018)			
Year -16	0.012 (0.005)	0.036** (0.014)	0.046*** (0.011)			
Year -15	0.002 (0.007)	-0.005 (0.011)	0.0003 (0.018)	0.142*** (0.049)		
Year -14	0.001 (0.007)	-0.011 (0.011)	-0.003 (0.012)	0.330*** (0.084)		
Year -13	-0.001 (0.005)	-0.007 (0.007)	-0.002 (0.011)	-0.114 (0.134)		
Year -12	0.001 (0.005)	0.009 (0.009)	0.021* (0.011)	0.047 (0.070)		
Year -11	-0.010** (0.004)	0.008 (0.007)	-0.016 (0.011)	-0.026 (0.092)		
Year -10	0.002 (0.005)	0.002 (0.007)	-0.004 (0.011)	-0.019 (0.084)		

Year -9	0.001 (0.003)	0.016* (0.009)	-0.007 (0.010)	-0.018 (0.084)		
Year -8	0.010 (0.004)	-0.002 (0.005)	0.002 (0.010)	-0.051 (0.066)	-0.035 (0.031)	-0.023 (0.031)
Year -7	-0.009** (0.004)	0.002 (0.007)	-0.004 (0.009)	0.001 (0.089)	-0.028 (0.041)	0.043* (0.025)
Year -6	-0.004 (0.003)	-0.004 (0.006)	-0.002 (0.009)	0.034 (0.066)	-0.021 (0.025)	0.017 (0.016)
Year -5	-0.005 (0.003)	-0.007 (0.007)	0.002 (0.008)	0.023 (0.043)	0.019 (0.019)	-0.006 (0.013)
Year -4	0.005 (0.004)	-0.005 (0.006)	0.018* (0.011)	-0.009 (0.041)	0.042* (0.022)	0.015 (0.014)
Year -3	0.001 (0.003)	0.004 (0.008)	-0.016 (0.011)	-0.003 (0.040)	-0.056* (0.033)	-0.003 (0.019)
Year -2	0.001 (0.004)	-0.004 (0.008)	-0.0003 (0.011)	0.004 (0.045)	0.019 (0.024)	0.020 (0.015)
Year -1	-0.003 (0.003)	-0.007 (0.007)	-0.021* (0.012)	-0.077* (0.043)	0.032 (0.022)	-0.010 (0.018)
Year 0	0.002 (0.003)	-0.018** (0.008)	0.004 (0.010)	0.029 (0.044)	-0.001 (0.022)	-0.003 (0.015)
Year 1	0.003 (0.007)	-0.017 (0.015)	0.037** (0.015)	0.007 (0.049)	0.006 (0.025)	-0.007 (0.009)
Year 2	0.007 (0.010)	-0.004 (0.022)	0.054*** (0.019)	0.010 (0.066)	0.006 (0.026)	-0.014 (0.016)
Year 3	0.002 (0.010)	-0.021 (0.021)	0.068*** (0.021)	0.092 (0.072)	0.033 (0.038)	-0.011 (0.015)
Year 4	0.018* (0.010)	-0.059** (0.024)	0.009 (0.025)	0.235** (0.114)	-0.006 (0.051)	0.008 (0.032)
Year 5	0.022* (0.013)	-0.053* (0.031)	0.007 (0.026)	0.012 (0.071)	-0.079 (0.066)	-0.006 (0.028)
Year 6	-0.001 (0.017)	-0.051** (0.023)	0.040 (0.030)	-0.0204 (0.054)		-0.024 (0.038)
Year 7	0.0001 (0.019)	-0.044 (0.032)	0.034 (0.044)	-0.014 (0.074)		
Year 8	-0.005 (0.021)	-0.096** (0.041)	-0.033 (0.047)	0.030 (0.105)		
Year 9	0.003 (0.023)	-0.083 (0.051)	-0.057 (0.052)	0.117 (0.135)		
Year 10	-0.017 (0.023)	-0.086* (0.048)	-0.029 (0.055)	-0.300** (0.132)		
Year 11	0.001 (0.021)	-0.071 (0.044)	0.001 (0.059)	-0.392* (0.210)		
Year 12	-0.017 (0.020)			-0.532*** (0.126)		
Year 13	-0.008 (0.023)			-0.264** (0.134)		

Obs.	1,207	988	988	802	893	207
Controls	Yes	Yes	Yes	Yes	Yes	Yes

*Note: This table displays result of staggered difference-in-difference model and event study. The sample is defined as mortality for the period 2013-2020 and the coal plant closure for the period 2000-2022 in the local authority in England. Parentheses contain the se. Significance Levels: * = 10%, ** = 5%, *** = 1%*

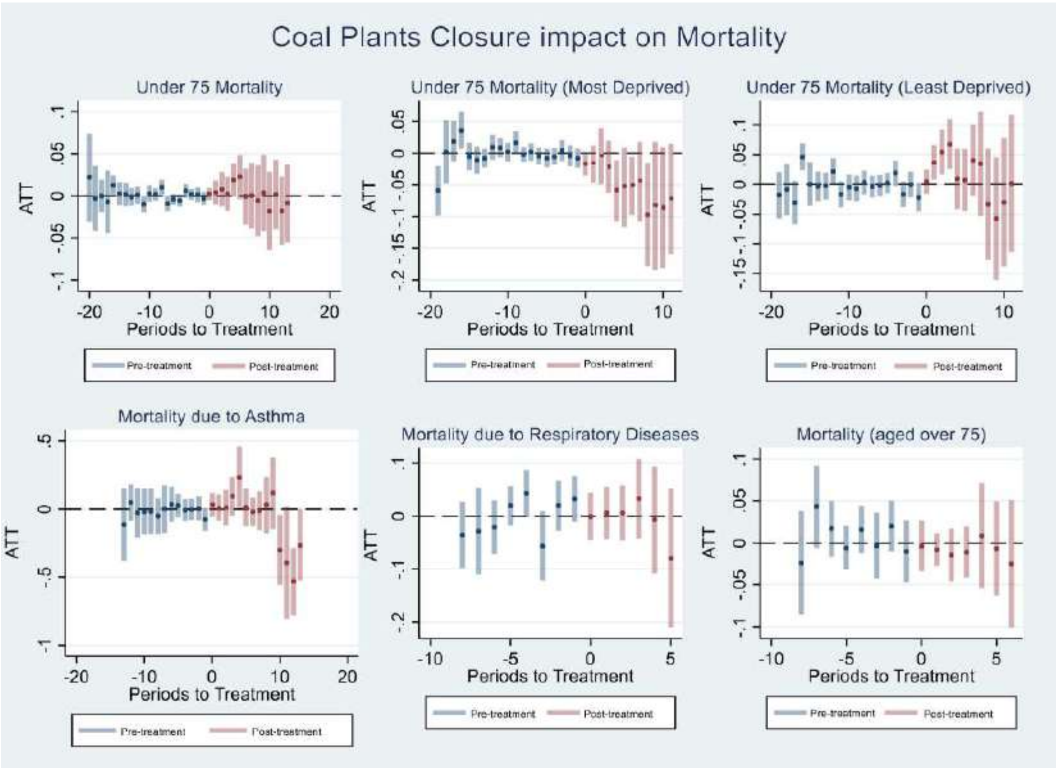

Figure 5. Event study of mortality due to closure of coal-fired power plants

4.2.3. Coal Plant Closures on Mental Health

To analyze the impact of coal plant closures on the mental health, we use mortality due to behavioral and mental health issues, suicide rate male, and suicide rate female, in logarithms. The covariates associated with mental health are deprivation rate and the share of 65 people.

The share of people aged 65 and above is used as control because it might be affecting the mortality due to mental illnesses, which might not be related to the coal plant closures. And deprivation rate might be impacting the mental health indirectly, so taking it as a control would lead to a more reliable result.

Table 5 reveals that, mortality due to diseases of behavioral and mental health reduced by 5.4% in the local authorities and in their neighboring where the coal plants are closed compared where it is not. There is a negative relationship which has been seen with the suicide rates of males and females with the coal plant closures, however, it is not significant.

Figure 6 depicts the potential parallel trends assumption. It shows that the mortality due to mental and behavior diseases starts to decrease after the treatment has occurred. Suicide rate among males and females does not exhibit any change after the treatment.

Table 5. Mental Health and Coal Plants Closure

	Mortality Due to Diseases of Mental and Behavioral	Suicide Rate Male	Suicide Rate Female
Differences in Differences Model			
Closures X Post	-0.054** (0.021)	-0.069 (0.057)	-0.011 (0.100)
Event Study			
Year -18		-0.411** (0.205)	-0.752*** (0.183)
Year -17		-0.193** (0.094)	0.373** (0.164)
Year -16		0.083 (0.055)	-0.045 (0.096)
Year -15		0.310 (0.227)	-0.178* (0.092)
Year -14		0.005 (0.044)	0.032 (0.104)
Year -13		-0.139 (0.098)	0.129** (0.063)
Year -12		0.012 (0.089)	-0.036 (0.085)
Year -11		-0.071 (0.071)	-0.068 (0.059)
Year -10		-0.017 (0.060)	-0.121** (0.057)
Year -9		-0.010 (0.056)	0.068 (0.072)
Year -8		0.043 (0.054)	-0.085 (0.086)
Year -7		0.076 (0.051)	-0.288** (0.146)
Year -6	0.201 (0.156)	-0.015 (0.026)	-0.237 (0.14)
Year -5	-0.086 (0.090)	0.009 (0.026)	-0.142* (0.080)
Year -4	-0.036 (0.023)	-0.097* (0.050)	0.199*** (0.055)
Year -3	-0.010 (0.030)	0.042 (0.036)	-0.119* (0.067)
Year -2	-0.012 (0.040)	-0.028 (0.035)	0.105** (0.046)
Year -1	0.124 (0.081)	0.073* (0.040)	0.030 (0.077)
Year 0	-0.048 (0.047)	-0.045 (0.029)	0.082 (0.062)

Year 1	-0.025 (0.022)	-0.084** (0.041)	0.016 (0.101)
Year 2	-0.064** (0.032)	-0.036 (0.068)	0.002 (0.177)
Year 3	-0.062 (0.041)	-0.005 (0.080)	0.036 (0.183)
Year 4	-0.031 (0.044)	-0.066 (0.086)	-0.105 (0.159)
Year 5	-0.180*** (0.027)	-0.012 (0.163)	-0.178 (0.292)
Year 6		-0.145 (0.151)	-0.228* (0.123)
Year 7		-0.121 (0.124)	-0.189 (0.211)
Year 8		-0.300*** (0.116)	-0.174 (0.214)
Year 9		-0.223 (0.192)	0 (omitted)
Year 10		-0.176 (0.110)	
Year 11		0.173* (0.100)	
Year 12		0.085 (0.083)	0 (omitted)
Obs.	184	637	457
Controls	Yes	Yes	Yes

*Note: This table displays result of staggered difference-in-difference model and event study. The sample is defined as mental health for the period 2001-2019 and for the coal plant closures from 2000-2022 in the local authority in England. Parentheses contain the se. Significance Levels: * = 10%, ** = 5%, *** = 1%.*

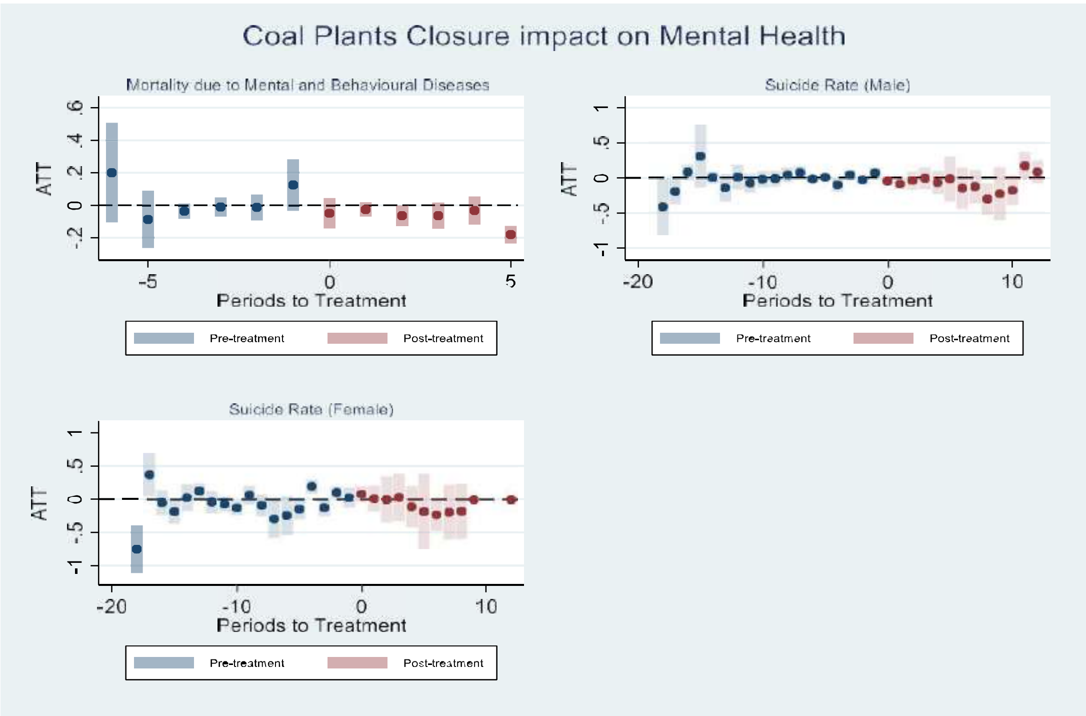

Figure 6. Event study of mental health due to closure of coal-fired power plants

5. Robustness Checks

5.1. Placebo Test

We did placebo tests to check that our empirical results are robust. In placebo test, we investigate whether the observe effects of the improvement in emissions and health outcomes were due to the treatment (here, closure of coal-fired power plants).

We run a Placebo treatment timing test in which we took treatment timing as 2 years before the actual treatment period. If we get the significant results, then it would mean that the improvement in emissions and health outcomes which we got due to the closure of the coal plants were not actually due to the closures but something else. However, if the results are insignificant, it would mean that the improvement in the emissions and health outcomes were indeed due to the closures, and this would eliminate the pre-existing trends. We construct the treatment timing as 2 years prior, meaning that if the plant has been closed in the year 2004, we assume that it closed on 2002, and so on.

As expected, our analysis (in appendix V) shows that there are no effects on emissions and health outcomes, due to closures in the placebo treatment timing. This implies that our causal inference results are robust.

5.2. Additional Analyses

5.2.1. Inclusion of all local authorities

We also run the analysis by including all the local authorities irrespective whether they have a coal plant or not. The inclusion of these local authorities will help in testing external validity and helps in addressing the potential bias. If the results are similar to that of the original results, it means our results are robust.

The appendix IV, show our findings of this analysis. The same variables which were significant before are significant now and with lower standard errors. We can infer that our results are robust, meaning that the coal plant closures are consistently associated with emissions reduction and health improvements, regardless of whether the areas included initially had direct coal plant exposure. This could strengthen the argument that the closures are driving the positive health outcomes rather than other location-specific factors.

In short, inclusion of these observations does not change our results, implying that the impact of coal plant closures on emissions and health outcomes is widespread, potentially due to dispersion of regional pollution.

5.2.2. Net Migration

Net migration here is defined as the total of inflows less outflows. If we take migration as an outcome variable, the closures of the coal-fired power plant do not change the net migration into the treated local authorities, as shown in appendix II. This implies that due to the closures of the coal-fired power plant people do not migrate to other local authorities, neither they go to the better local authorities, which now have the less pollution. This implies that our results are not diluted with the migration of individuals, but with rather pure health impacts.

5.2.3. Unemployment

Unemployment has not been impacted by the closure of the coal-fired power plants, as shown by the results in appendix I. This implies that the coal power plants, does not employ significantly large number of people, which after phase-out are not significantly impacted.

6. Discussion

The primary objective of this paper is to investigate the causal relationship between coal-fired power plants closure on the health outcomes in England. Our period of analysis is from 2000 to 2022, when major coal-fired power plants were closing. And one of the main policies during our period of analysis is the Carbon Tax Policy (2013), which was introduced in the United Kingdom. The main objective of our research is not finding out the impact of the policy change in England but in understanding one key targets of that policy, which is closures of the coal-fired power plants in England. Emissions from coal-fired power plants like PM10, nitric oxides, and nitrogen dioxide, directly impacts the cardiovascular and respiratory morbidity and mortality of the population as it leads to oxidative stress and inflammation (Anderson, Thundiyil, & Stolbach, 2012). Therefore, it is crucial to conduct research analyzing the impact of coal plant closures on health outcomes through the mechanism, emissions that they release. Our analysis focusses only in England, as it has the maximum coal-fired power plants and the rest 3 countries in the UK do not have enough coal power plants, that we could do the causal inference.

We have found some evidence from our estimation analysis and it is consistent with the previous literature that coal-fired plants have a direct impact on emissions like nitrogen dioxide, nitric oxides, and PM10. The results from emissions show that the overall ATT for the levels of nitrogen dioxide have reduced by 4.429 micrograms, on average, in each cubic meter of air (µg m-3) in the focused local authority and its neighboring compared to the local authorities and its neighboring which did not have the coal plants. This is consistent with the studies that coal plant closures lead to a reduction in emissions (Shon, Kang, Park, & Bae 2020; Russell, Belle, & Liu 2017).

While nitric oxide decreased for 3 periods after the closures and then it again increased. Report on Greenhouse Gas Emissions (2022) revealed that there has been change in the proportion of greenhouse gas emissions from power stations, which were highest 10 years ago to domestic transport sector, which became highest since 2014 (National Statistics, 2024). The main source of nitrous oxide are coal, domestic transportation, and agriculture. Moreover, emissions from domestic transportation increased between the years 2013 and 2017; and emissions from agriculture sector stayed at the similar level from 2000's (National Statistics, 2024). All these factors could have contributed to an initial decline followed by an increase in nitric oxide levels.

Moreover, PM10 decreased in the 3rd period after the closure of the coal plant then it again increased. A report by National Statistics (2024), revealed that a decrease in emissions from power sector has been offset by a rise in emissions from burning of wood in domestic settings and solid fuel burning in the industry (particularly the burning of biomass based-fuels). Biomass based-fuels proportion contributed PM2.5 emissions have increased from less than 1% before 2009 to 6% in 2022 (National statistics, 2024). This could have offset the decrease of emissions from coal plants closure.

This research further finds that the hospital admissions for respiratory and hospital admissions for asthma (among above 19) have declined by 4.1% and 10.7% respectively, which is consistent with the previous studies (Martenies, Akherati, Jathar, & Magzamen, 2019).

Furthermore, the results also show that mortality for people aged under 75 who are most deprived has reduced. Closure of coal plants lead to, on average, 3.56% less deaths for under 75 most deprived people in the local authorities which has closed the coal plants and their neighboring local authorities, compared to local authorities and its neighbor where the coal plant has not been closed. It could be the reason that the most deprived people are more prone to air pollution, and might be living near the coal-fired plants. Due to the closure of the coal plants their environmental conditions improved as a result; their mortality decreased.

The 5.4% reduction in deaths from mental and behavioural disorders fills a research gap pointed out by Martenies, Akherati, Jathar, and Magzamen (2019), who noted the limitation of not analyzing neurocognitive effects. However, the suicide rate among males and females are not significant. The factors affecting suicide rate could be due to two reasons in this context. Firstly, there is a negative relationship between emissions and mental health implying, a reduction in emissions would improve mental health (Lawrance, Thompson, Fontana, & Jennings, 2021). Moreover, as the coal plants are closed in the local authority, there would have been more cases of unemployment. The studies indicated that there is a negative effect of unemployment on the mental health, unemployment leads to poor mental health (Murphy & Athanasou, 1999). And since, we found insignificant unemployment rates, due to closure of coal plants, so the first rational might be over-powering here and making it negative but insignificant.

These important findings show us that the closure of coal-fired power plants indeed improve the health outcomes of the people living close to them. The limitations this paper include limited data units, which is available for only some years for some of the health variables. Consequently, there is a decade-long gap between available data points. Additionally, this study did not encompass the financial benefits resulting from improved health outcomes, nor did it delve into the economic repercussions of coal plant closures on the income of employees working in coal power generation units. These aspects lie beyond the scope of our paper.

7. Conclusion

The study evaluates the effect of coal plants closures on the health outcomes of the people living in England. The study analyzed the local authorities where the coal plant has been closed and its neighboring local authorities and the health status of the people with the people living in the local authorities in which the coal plant has not been closed and its neighboring local authority. We have used the emission as the mechanism through which we find the relationship between coal plant closures and its impact on the health outcomes. The study has implemented Staggered Difference-in-Difference approach to acknowledge the difference in treatment timings.

The main results shows that the emissions have been reduced over the years, as coal plants got closed. The significant drop has been seen in the emissions of nitrogen dioxide, which is around 15.2% due to the closure of the coal-fired power plants. The health outcomes also improved, as hospital admissions for respiratory declined, on average, by 4.1% and hospital admission for asthma (aged 19 above), on average, declined by 10.7%, in the local authorities where they closed the coal plant and its neighboring local authorities. The mortality rate among under 75 most deprived decreased, on average, by 3.5% in those local authorities over the years. Finally, mortality due mental diseases also fell by 5.4%, on average, in the local authorities and its neighbor which have closed the coal plants.

The research suggests a positive impact on the overall health outcomes of the people in the main local authority and it's neighboring over the years due to the coal plant closures. Further study on longitudinal data would be needed to find out the relevant impact of coal plants closure on mortality.

This research could be an important tool for the government in decision-making of weighing the pros and cons of having a coal plants. Our study did not estimate the impact of coal-fired power plants on the income of the workers employed in this sector, however, it focused on the related health outcomes on the people. Further, health is the most important aspect of life, if people are healthy, then they are considered efficient. They would be more efficient in terms of working; they would not need to visit the healthcare centers frequently which saves their time and money. As a result, it would be better for everyone in the country. More healthy people help in generating more efficient outcome; however, labor efficiency was not in our scope of research, which could be a scope for the future research.

Non-renewable energy sources like coal present pressing challenges to global health, encompassing both physical and mental well-being, which the world economy must address in the coming years. The significance of this research lies in its ability to offer valuable insights for policy decisions and public health interventions. Through an exploration of the impact of coal plant closures on health outcomes, including reduced air pollution and enhanced respiratory health, this study has the potential to inform policymakers striving to advance public health and environmental sustainability goals. Furthermore, by delving into the economic and social consequences of such closures, it enables the development of strategies to alleviate negative effects on affected communities. Ultimately, this research contributes to evidence-based decision-making aimed at improving public health and environmental well-being, thereby underscoring its relevance in the realms of environmental policy and public health advocacy.

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Appendix

I. Causal relationship between unemployment and the closure of coal-fired power plants in England

We need to check if unemployment has a causal relationship with the coal plant closures. We analyse the unemployment on the coal plant closures. We have included population and IMD score as a covariate in this analysis. We get this result.

Table 7 shows that the unemployment gets significant from the 10th period till 12th period after the closure of the coal-fired power plants. However, the overall ATT is not significant for all the periods, on average.

Figure 8 shows the potential parallel trends in unemployment due to the closure of coal-fired power plants. The unemployment starts to increase from the 10th period then it peaked in the 11th period, then it starts to fall. It remained positive and significant in the 12th period as well, however, in the 13th period, it becomes negative.

Table 6. Unemployment and Coal Plants Closure

	Unemployment
Differences in Differences Model	
Closures X Post	0.038 (0.341)
Event Study	
Year -17	0.576 (0.574)
Year -16	0.363 (0.931)
Year -15	0.659416 (0.605)
Year -14	-0.741434 (1.048)
Year -13	0.2100609 (0.570)
Year -12	-0.047884 (1.074)
Year -11	-0.727703 (0.555)
Year -10	-0.270075 (0.635)
Year -9	0.9315118** (0.417)
Year -8	0.1626377 (0.348)
Year -7	-0.035999 (0.592)

Year -6	0.3162919 (0.515)
Year -5	-0.084417 (0.405)
Year -4	-0.516488 (0.362)
Year -3	-0.437874 (0.375)
Year -2	-0.047343 (0.336)
Year -1	0.9245242** (0.389)
Year 0	-0.252866 (0.415)
Year 1	0.028886 (0.391)
Year 2	-0.46708 (0.422)
Year 3	0.1218414 (0.332)
Year 4	0.2088317 (0.443)
Year 5	0.995703 (0.802)
Year 6	-0.527923 (0.566)
Year 7	-0.366645 (0.656)
Year 8	-0.07379 (0.929)
Year 9	0.5325032 (0.947)
Year 10	1.315615** (0.640)
Year 11	2.953612*** (1.118)
Year 12	1.886802*** (0.710)
Year 13	-0.464132 (1.013)
Obs.	1054
Controls	Yes

*Notes. This table displays result of staggered difference-in-difference model and event study. The sample is defined as unemployment for the period 2004-2022 and for the coal plant closures from 2000-2022 in the local authority in England. Parentheses contain the se. Significance Levels: * = 10%, ** = 5%, *** = 1%*

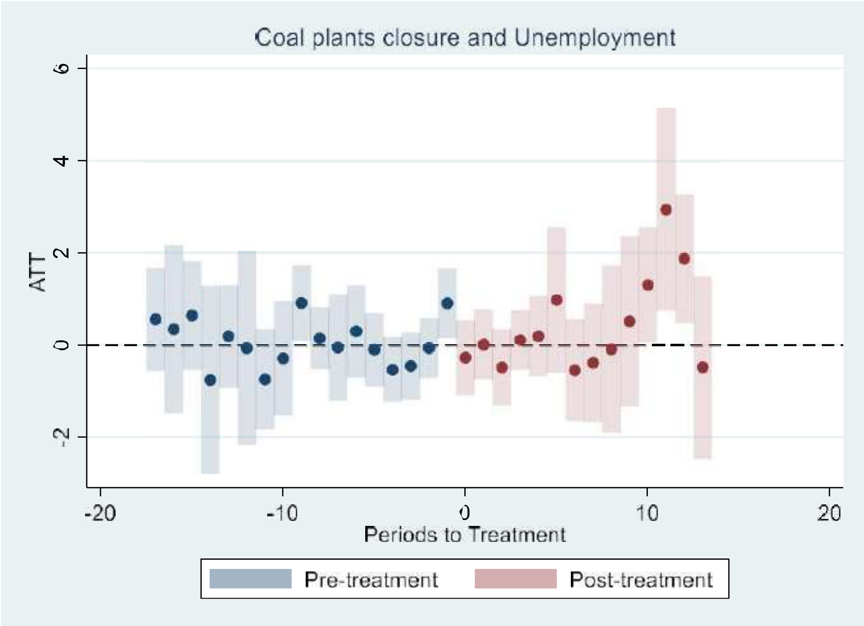

Figure 7. Potential Parallel Trends in unemployment

II. Coal Closures impact on Net Migration

Table 7. Net Migration and Coal Plants Closure

	Net Migration
Differences in Differences Model	
Closures X Post	-0.180 (0.131)
Event Study	
Year -11	0.103 (0.159)
Year -10	-0.584* (0.340)
Year -9	-0.038 (0.431)
Year -8	0.260 (0.303)
Year -7	-0.408 (0.268)
Year -6	-0.122 (0.215)
Year -5	-0.223 (0.164)
Year -4	-0.039 (0.184)

Year -3	0.148 (0.197)
Year -2	0.075 (0.194)
Year -1	0.024 (0.160)
Year 0	-0.139 (0.119)
Year 1	-0.210 (0.185)
Year 2	-0.102 (0.174)
Year 3	-0.054 (0.228)
Year 4	-0.356 (0.254)
Year 5	-0.200 (0.318)
Year 6	-0.384 (0.235)
Year 7	-0.194 (0.278)
Year 8	0.034 (0.310)
Obs.	1718
Controls	Yes

*Note: This table displays result of staggered difference-in-difference model and event study. The sample is defined as net migration for the period 2010-2019 and the coal plant closures from 2000-2022 in the local authorities in England. Parentheses contain the se. Significance Levels: * = 10%, ** = 5%, *** = 1%.*

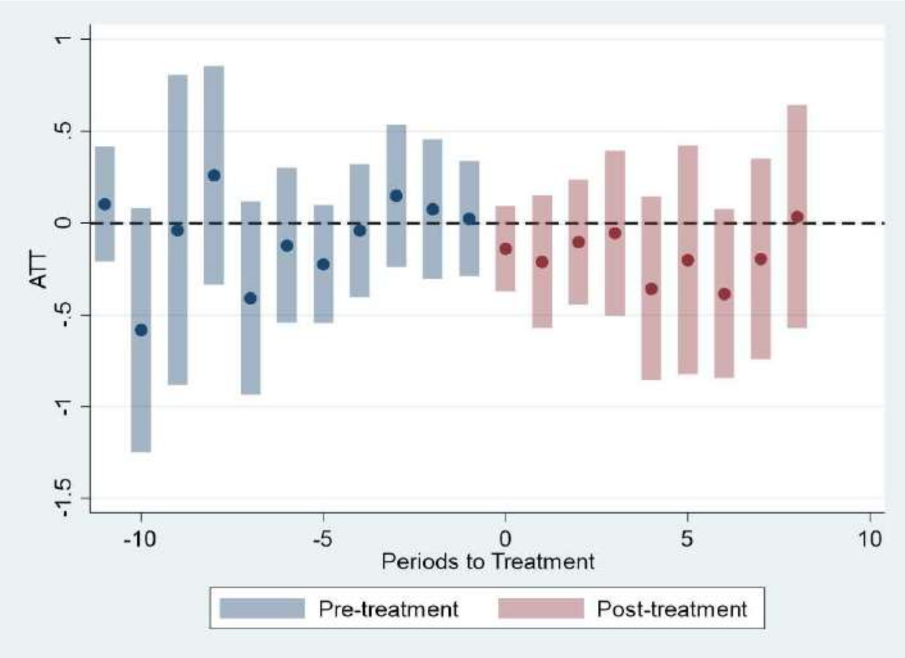

Fig 8. Event Study: Coal closures impact on Net Migration

III. These emission results are in logarithms.

Table 8. Emissions and coal plant closures (in logarithms)

	Nitrogen Dioxide (NO2)	Nitric Oxide (NO)	PM10
Differences in Differences Model			
Closures X Post	-0.152*** (0.054)	-0.088 (0.192)	-0.038 (0.438)
Event Study Model			
Year -13	-0.084* (0.046)	-0.017 (0.074)	0.031 (0.021)
Year -12			0.018 (0.015)
Year -11	-0.029 (0.030)	-0.265** (0.087)	0.022 (0.033)
Year -10	-0.031 (0.072)	0.250 (0.217)	-0.059* (0.030)
Year -9	0.094* (0.055)	-0.236 (0.167)	-0.023 (0.021)
Year -8	0.004 (0.047)	-0.116* (0.060)	0.001 (0.020)
Year -7	-0.005 (0.191)	-0.280 (0.228)	-0.046 (0.037)
Year -6	-0.109 (0.102)	0.101 (0.190)	-0.058 (0.066)
Year -5	0.069 (0.058)	0.031 (0.091)	-0.010 (0.035)
Year -4	0.049 (0.078)	0.054 (0.074)	0.015 (0.035)

Year -3	-0.040 (0.063)	-0.019 (0.084)	0.072 (0.049)
Year -2	-0.048 (0.042)	-0.094 (0.075)	-0.034 (0.066)
Year -1	0.061 (0.043)	0.099 (0.094)	0.028 (0.047)
Year 0	-0.027 (0.076)	0.109 (0.080)	0.0004 (0.053)
Year 1	-0.110** (0.047)	-0.129 (0.129)	-0.035 (0.133)
Year 2	-0.135*** (0.039)	-0.085 (0.081)	-0.131 (0.148)
Year 3	-0.311*** (0.092)	-0.321*** (0.081)	-0.091 (0.059)
Year 4	-0.365*** (0.062)	-0.255* (0.136)	-0.061 (0.075)
Year 5	-0.186*** (0.024)	-0.400*** (0.052)	0.019** (0.008)
Year 6	-0.228*** (0.031)	-0.309*** (0.068)	0.033*** (0.012)
Year 7	-0.169*** (0.039)	0.122** (0.058)	-0.105*** (0.016)
Obs.	410	410	374
Controls	Yes	Yes	Yes

*Notes. This table displays result of staggered difference-in-difference model and event study. The sample is defined as emissions in the local authority and coal plant closure from 2000-2022 in England. Parentheses contain the p-value. Significance Levels: * = 10%, ** = 5%, *** = 1%*

IV. This includes the results for Control 2: All the local Authorities included irrespective of having a coal plant or not.

1. Hospital Admissions

Table 9. Hospital Admissions (control2) (in logarithms)

	Emergency Hospital Admissions for Respiratory Diseases	Emergency Admissions for Children with lower tract infections	Hospital Admissions for Asthma) (aged 19 years and over)	Hospital Admissions for Asthma) (aged under 19)
Difference-in-Difference Model				
Closures X Post	-0.038*** (0.012)	-0.064 (0.042)	-0.074* (0.031)	0.044 (0.043)
Event Study				
Year -8	-0.013099 (0.0253449)	0.0340801 (0.0509884)	-0.0429573 (0.0556719)	0.0908005** (0.0361001)
Year -7	-0.0117598 (0.0278922)	-0.0591804 (0.1411807)	0.1243739 (0.0795393)	-0.1289544 (0.0926188)
Year -6	0.008205 (0.0112852)	0.0834916* (0.0437206)	0.0609106** (0.0292693)	0.028003 (0.0348506)

Year -5	-0.0074152 (0.0112127)	-0.0877633 (0.0604025)	-0.0219352 (0.032706)	0.0456676 (0.0361256)
Year -4	-0.0128612 (0.0099194)	-0.0435478 (0.0492223)	0.0142787 (0.045875)	-0.1588*** (0.043565)
Year -3	0.001143 (0.018456)	0.013868 (0.0340152)	-0.0615586* (0.0351929)	0.0145339 (0.0395125)
Year -2	0.0073579 (0.0172274)	-0.0085806 (0.038024)	0.0697426** (0.0348634)	-0.0287416 (0.0402403)
Year -1	0.017407 (0.0116232)	0.0713098* (0.0382686)	0.0461265 (0.0286925)	-0.013746 (0.0346974)
Year 0	-0.0254875 (0.0130897)	-0.0209127 (0.0396623)	-0.0705366*** (0.0269486)	0.0435643 (0.0364365)
Year 1	-0.0277626* (0.0145467)	-0.0468185 (0.0575074)	-0.0920562* (0.0477126)	0.0577187 (0.0422561)
Year 2	-0.0600844*** (0.0209591)	-0.1418456** (0.0591607)	-0.0872853** (0.0429965)	-0.0376582 (0.0793473)
Year 3	-0.0639464*** (0.0206059)	-0.0942127 (0.0788877)	-0.1336733*** (0.047917)	0.0182081 (0.0761865)
Year 4	-0.0130238 (0.0174266)	0.1265268 (0.0798876)	-0.0513825 (0.0522912)	0.1013096 (0.0803028)
Year 5	-0.0730579*** (0.023962)	-0.4167601*** (0.0673656)	0.0887614 (0.0826496)	0.1850164*** (0.0508023)
Obs.	2,123	2,100	2,123	2,122
Controls	Yes	Yes	Yes	Yes

*Notes. This table displays result of staggered difference-in-difference model and event study. The sample is defined as hospital admissions in the local authority for the period 2013-2020 and coal plant closure from 2000-2022 in England. Parentheses contain the p-value. Significance Levels: * = 10%, ** = 5%, *** = 1%*

2. Mortality

Table 10. Mortality (control2)

	l(Under 75 Mortality)	Under 75 Most Deprived (with pop as covariate)	Under 75 Least Deprived (with pop as covariate)	Log (Mortality due to Asthma)	Mortality Due to Respiratory Diseases	Mortality Over 75 years
Differences in Differences Model						
Closures X Post	-0.0082394 (0.0085337)	-24.3006*** (8.420592)	1.628688 (4.945315)	0.082995** (0.0378458)	5.84747 (12.73326)	-22.82875 (36.07144)
Event Study						
Year -20	0.0173049 (0.0131714)					
Year -19	-0.0218373** (0.0105387)	-37.0695*** (9.276531)	-1.363121 (5.747931)			
Year -18	-0.0068214 (0.0065338)	-11.10936 (9.355794)	-1.294364 (8.435937)			
Year -17	0.001989 (0.0060102)	-0.7697263 (9.123552)	-5.972813 (4.409421)			

Year -16	0.0079617 (0.0053417)	12.25721*** (4.317784)	7.43316** (3.248185)			
Year -15	-0.0018724 (0.0048122)	-5.10187 (4.570212)	-5.799491 (4.325721)	0.1038606 (0.0639404)		
Year -14	-0.000719 (0.004177)	-1.663013 (6.461924)	-0.7688024 (3.336677)	0.2180543*** (0.0319445)		
Year -13	0.0000163 (0.0036387)	-4.374816 (3.829981)	0.6752391 (3.017983)	-0.1358644 (0.0945772)		
Year -12	0.0024916 (0.0039461)	3.242585 (3.940093)	1.600352 (2.961856)	0.0021402 (0.0555684)		
Year -11	-0.0056609 (0.0035346)	-1.797862 (3.95316)	-6.08901** (2.85825)	0.0574397 (0.072742)		
Year -10	0.0023235 (0.003682)	3.111859 (3.485671)	-3.020148 (2.701099)	-0.0245674 (0.0513288)		
Year -9	0.0027103 (0.0034222)	3.645172 (3.680561)	1.973191 (2.189796)	0.044198 (0.0604079)		
Year -8	0.0026797 (0.0032939)	1.865357 (3.206553)	0.1915735 (2.530556)	-0.0693691 (0.0407578)	-15.6830*** (4.987302)	-20.52542 (35.02539)
Year -7	-0.0073365** (0.0034998)	2.240393 (3.335245)	-0.9030412 (2.16475)	0.0617397 (0.0504412)	5.517335 (13.06632)	-45.9491** (23.22522)
Year -6	-0.003384 (0.0029435)	1.166795 (2.942403)	-2.848005 (1.901245)	-0.0078891 (0.0387239)	-14.32246 (10.86676)	2.409266 (18.01078)
Year -5	-0.0010432 (0.0026936)	-3.558003 (3.52518)	1.279891 (2.011056)	0.0404175 (0.0255675)	13.17756 (9.317124)	-54.7633** (23.30975
Year -4	0.0060682* (0.0031933)	-2.383874 (3.305248)	3.941545 (2.556598)	-0.04485* (0.0233293)	10.66738 (9.223735)	10.33822 (29.8655)
Year -3	-0.0000441 (0.0026817)	2.765033 (3.760271)	-3.282357 (2.647319)	-0.0060661 (0.03413)	-16.03319 (10.68294)	13.32222 (31.59422)
Year -2	0.0007279 (0.0037675)	-0.9752341 (3.654285)	-0.7045858 (2.295381)	0.0568936 (0.0378081)	5.200663 (8.174642)	-23.83192 (21.81487)
Year -1	-0.0025083 (0.0040844)	-2.730378 (3.531299)	-5.44495** (2.650412)	-0.1150603*** (0.0344063)	4.49513 (9.361184)	8.948427 (19.03501)
Year 0	-0.0002209 (0.0037494)	-10.20149** (4.55799)	1.225108 (2.50306)	0.0651374* (0.0386248)	2.512814 (12.66429)	-33.20883 (27.46488)
Year 1	-0.0038374 (0.0073457)	-9.036948 (7.133794)	7.412298 (3.240193)	0.0204818 (0.039689)	14.43807 (15.38216)	-37.82925 (30.06306)
Year 2	-0.0024378 (0.0093065)	-3.125412 (10.89656)	8.861494* (4.764169)	0.0854814** (0.0408163)	8.051915 (11.09015)	-2.188454 (36.90559)
Year 3	-0.0035061 (0.0087444)	-14.97426 (10.1986)	10.95732** (5.232579	0.1018236*** (0.0366183)	19.36653 (15.75231)	-12.35836 (38.86352)
Year 4	0.0095954 (0.0093138)	-46.3914*** (11.8293)	-2.785211 (7.541102)	0.121603** (0.0517532)	0.7778002 (23.51092)	30.3974 (46.71459)
Year 5	0.0092519 (0.0137879)	-45.2353*** (13.52128)	-0.5232307 (7.460553)	0.1415061*** (0.0444227	-26.21206 (26.86487)	-30.38333 (90.06567)
Year 6	-0.025531 (0.0176546)	-40.1821*** (12.05591)	1.957002 (8.159666)	0.1834766*** (0.0573135)		-77.98333 (121.2199)

Year 7	-0.0188391 (0.020453)	-33.78241** (16.21655)	3.870032 (10.9014)	0.155603** (0.0616347)		
Year 8	-0.019455 (0.019871)	-55.4867*** (18.43476)	-14.26804 (10.5098)	0.1673611 (0.1026352)		
Year 9	-0.0194926 (0.0239696)	-53.6959*** (19.37308)	-18.85468* (11.11537)	0.0544069 (0.0870418)		
Year 10	-0.058522** (0.0236002)	-57.3115*** (17.42597)	-16.16176 (12.38575)	-0.1911352 (0.1326841)		
Year 11	-0.0447006 (0.0207728)	-50.0310*** (17.77402)	-11.1361 (14.41416)	-0.2893884 (0.2461871)		
Year 12	-0.045647*** (0.0167121)			-0.2726171*** (0.0752923		
Year 13	-0.0317366** (0.0149195)			-0.2998847*** (0.0543154)		
Obs.	4,721	3,887	3,887	3,863	898	1,260
Controls	Yes	Yes	Yes	Yes	Yes	Yes

*Notes. This table displays result of staggered difference-in-difference model and event study. The sample is defined as mortality for the period 2013-2020 and the coal plant closure for the period 2000-2022 in the local authority in England. Parentheses contain the se. Significance Levels: * = 10%, ** = 5%, *** = 1%*

3. Mental Health

Table 11. Mental Health (control 2)

	Mortality Due to Diseases of Mental and Behavioural YC1_ALL	Log(Suicide Rate Male) YC1_ALL	Log(Suicide Rate Female) YC1_ALL
Differences in Differences Model			
Closures X Post	-1.713427 (4.536697)	-0.04889 (0.039002)	0.045182 (0.082286)
Event Study			
Year -20		-0.0654*** (0.0318101)	0.256123*** (0.0318101)
Year -19		0.154748*** (0.0267383)	-0.17064*** (0.0267383)
Year -18		-0.02809 (0.040714)	-0.04168 (0.079567)
Year -17		0.061844 (0.04266)	-0.04148 (0.069371)
Year -16		0.053918* (0.0320191)	0.062209 (0.05373)
Year -15		0.038419 (0.036926)	-0.04277 (0.041646)
Year -14		-0.01559 (0.033191)	0.117847* (0.0646834)
Year -13		0.001392 (0.027353)	0.02365 (0.066056)
Year -12		0.018079 (0.031672)	0.007404 (0.044782)
Year -11		0.007667 (0.029371)	0.020989 (0.047077)
Year -10		-0.03097 (0.033251)	-0.04067 (0.045436)
Year -9		0.037125 (0.030221)	0.075029 (0.057497)
Year -8	-6.54392 (15.32777)	-0.01164 (0.022899)	0.031584 (0.044241)
Year -7	-0.9020199 (7.375724)	0.052108** (0.0260583)	0.05971 (0.053746)
Year -6	-3.131446 (6.706624)	-0.05217** (0.0238365)	-0.00699 (0.050516)
Year -5	9.022464** (4.340394)	0.007344 (0.027225)	0.019285 (0.041798)
Year -4	-0.6219845 (6.226665)	-0.07592*** (0.0288497)	0.070421* (0.0373377)

Year -3	10.85957 (8.060079)	0.050165 (0.031721)	0.014 (0.041572)
Year -2	4.816517 (5.363124)	-0.01402 (0.029558)	0.025074 (0.02748)
Year -1	3.672716 (4.916108)	0.059848*** (0.0225954)	-0.03334 (0.041396)
Year 0	2.619226 (8.606192)	-0.03251 (0.032081)	0.062736 (0.050749)
Year 1	2.050444 (8.151607)	-0.05587 (0.036353)	0.09913 (0.096177)
Year 2	-8.240946 (8.049459)	-0.02683 (0.044295)	0.147944 (0.150505)
Year 3	-1.32557 (7.586363)	-0.06042 (0.060094)	0.093776 (0.163582)
Year 4	0.0860734 (6.604517)	-0.0355 (0.058455)	-0.03765 (0.120896)
Year 5	-21.09234* (10.99739)	-0.05568 (0.081558)	-0.1672*** (0.0513381)
Year 6		-0.07043 (0.092588)	-0.13364 (0.120387)
Year 7		-0.0571 (0.096664)	0.048706 (0.147036)
Year 8		-0.20637** (0.0983968)	0.020762 (0.156508)
Year 9		-0.12166 (0.147686)	-0.30421*** (0.0889066)
Year 10		-0.06563 (0.097074)	
Year 11		0.16832*** (0.0624142	
Year 12		0.108493 (0.067373)	-0.35938*** (0.0767026)
Obs.	898	2,254	1,695
Controls	Yes	Yes	Yes

*Notes. This table displays result of staggered difference-in-difference model and event study. The sample is defined as mental health for the period 2001-2019 and for the coal plant closures from 2000-2022 in the local authority in England. Parentheses contain the se. Significance Levels: * = 10%, ** = 5%, *** = 1%*

V. Robustness Checks - Placebo Tests

IV.1. Emissions

Table 12. Emissions and placebo treatment-timing

	Nitrogen Dioxide (NO2)	Nitric Oxide (NO)	PM10
Differences in Differences Model			

Closures X Post	-0.042 (0.044)	-0.039 (0.101)	-0.034 (0.052)
Event Study Model			
Year -11	-0.084* (0.046)	-0.017 (0.074)	0.031 (0.021)
Year -10			0.018 (0.015)
Year -9	-0.029 0.031	-0.265*** (0.087)	0.022 (0.033)
Year -8	-0.031 (0.072)	0.250 (0.217)	-0.059* (0.030)
Year -7	0.094* (0.055)	-0.236 (0.167)	-0.023 (0.021)
Year -6	0.004 (0.047)	-0.116* (0.060)	0.001 (0.020)
Year -5	-0.005 (0.191)	-0.280 (0.228)	-0.046 (0.037)
Year -4	-0.109 (0.102)	0.101 (0.190)	-0.058 (0.066)
Year -3	0.069 (0.058)	0.031 (0.091)	-0.010 (0.035)
Year -2	0.049 (0.078)	0.054 (0.074)	0.015 (0.035)
Year -1	-0.040 (0.063)	-0.019 (0.084)	0.072 (0.049)
Year 0	-0.048 (0.042)	-0.094 (0.075)	-0.034 (0.066)
Year 1	0.029 (0.049)	0.082 (0.112)	-0.018 (0.066)
Year 2	0.068 (0.053)	0.139 (0.158)	-0.011 (0.036)
Year 3	-0.084 (0.051)	-0.056 (0.134)	-0.029 (0.176)
Year 4	-0.100 (0.044)	-0.096 (0.166)	-0.140 (0.176)
Year 5	-0.176*** (0.043)	-0.294** (0.133)	-0.159 (0.102)
Year 6	-0.282*** (0.034)	-0.403*** (0.083)	-0.099 (0.078)
Year 7	-0.133*** (0.033)	-0.376*** (0.067)	0.092*** (0.011)
Year 8	-0.177*** (0.034)	-0.254*** (0.059)	0.120*** (0.014)
Year 9	-0.107*** (0.040)	0.123 (0.111)	0.002 (0.020)
Obs.	398	398	366
Controls	Yes	Yes	Yes

Notes. This table displays result of staggered difference-in-difference model and event study. The sample is defined as emissions in the local authority and placebo treatment-timing of coal plant closure from 2000-2022 in England. Parentheses contain the p-

*value. Significance Levels: * = 10%, ** = 5%, *** = 1%.*

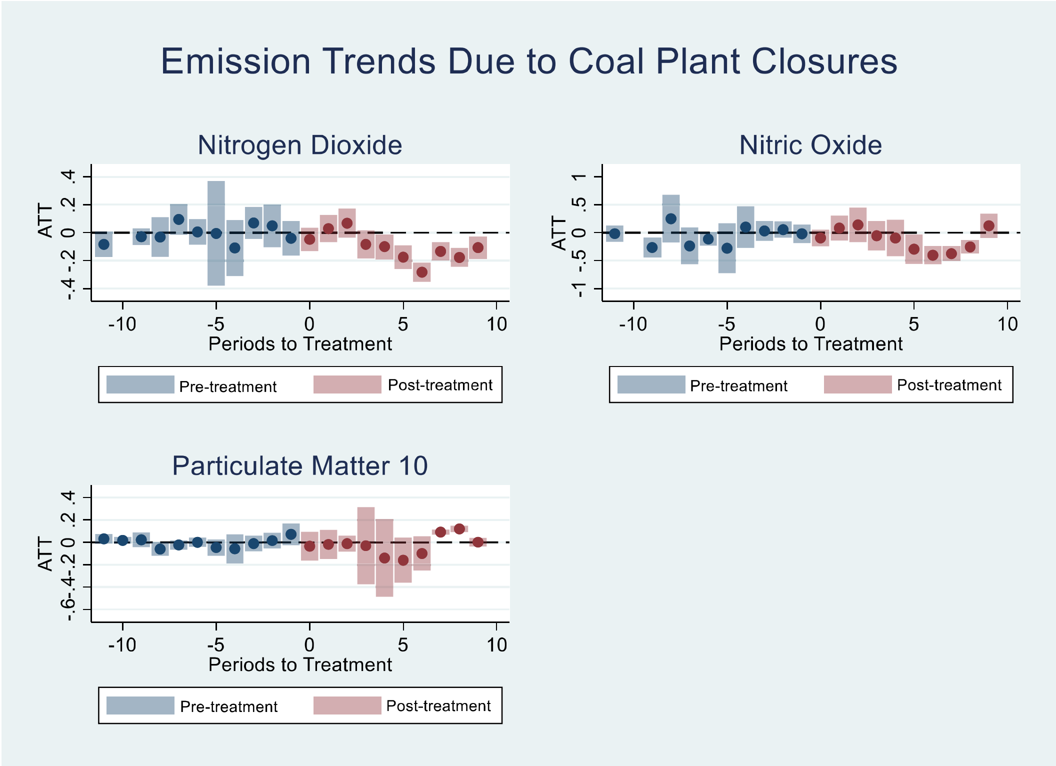

Figure 8. Event study of emissions due to placebo treatment-timing

IV.2. Hospital Admissions

Table 13. Hospital Admissions and placebo treatment-timing

	Emergency Hospital Admissions for Respiratory Diseases	Emergency Admissions for Children with lower tract infections)	Hospital Admissions for Asthma (aged 19 years and over)	Hospital Admissions for Asthma (aged under 19)
Difference-in-Difference Model				
Closures X Post	0.007 (0.023)	-0.039 (0.588)	0.050 (0.063)	-0.108 (0.113)
Event Study				
Year -4	0.082 (0.056)	-0.101 (0.108)	0.080 (0.079)	-0.183*** (0.064)
Year -3	0.063* (0.035)	0.372** (0.164)	-0.268*** (0.089)	0.275*** (0.092)
Year -2	0.009 (0.017)	-0.141* (0.085)	0.035 (0.052)	-0.196** (0.098)
Year -1	0.011 (0.031)	0.062 (0.110)	0.018 (0.108)	-0.073 (0.059)
Year 0	-0.008 (0.021)	-0.037 (0.062)	0.088* (0.049)	0.009 (0.043)

Year 1	0.003 (0.025)	-0.021 (0.106)	0.150** (0.060)	0.054 (0.066)
Year 2	-0.018 (0.036)	0.045 (0.093)	-0.016 (0.087)	-0.126 (0.098)
Year 3	-0.103** (0.042)	-0.021 (0.081)	-0.137 (0.131)	-0.228* (0.135)
Year 4	0.149*** (0.057)	-0.037 (0.224)	0.012 (0.149)	-0.461 (0.381)
Year 5	0.085 (0.084)	-0.251 (0.273)	-0.013 (0.103)	-0.438 (0.411)
Obs.	196	196	196	196
Controls	Yes	Yes	Yes	Yes

*Note: This table displays result of staggered difference-in-difference model and event study. The sample is defined as hospital admissions in the local authority for the period 2013-2020 and placebo treatment timing of the coal plant closures from 2000-2022 in England. Parentheses contain the se. Significance Levels: * = 10%, ** = 5%, *** = 1%*

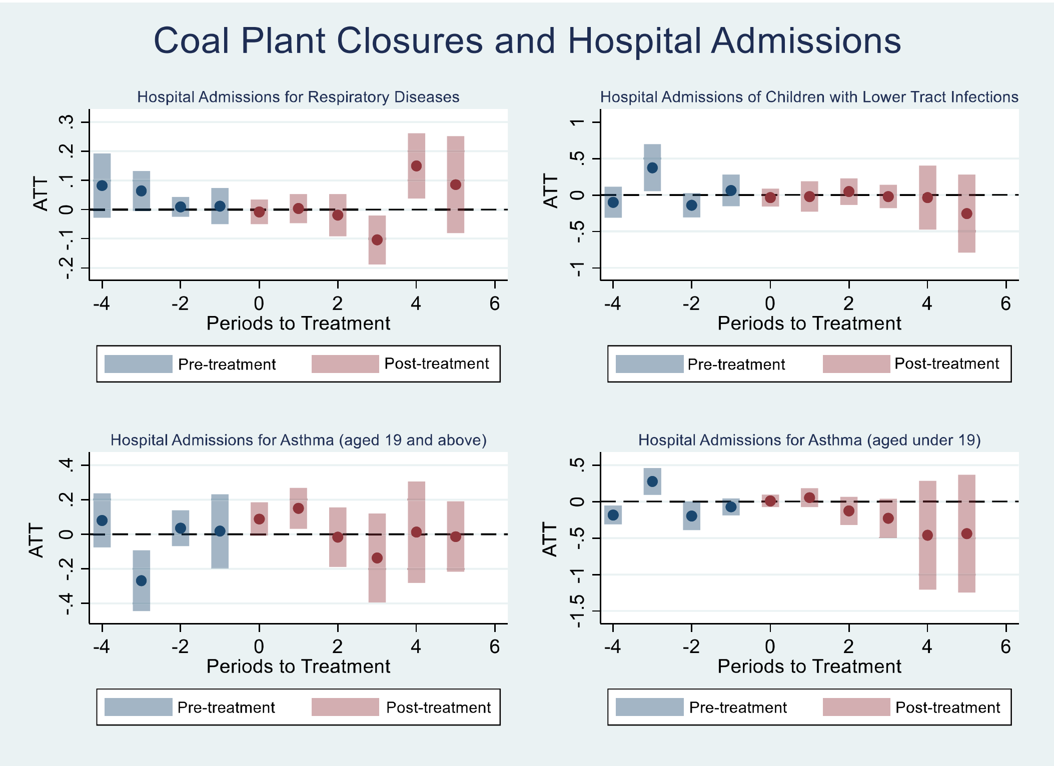

Figure 9. Event study of hospital admissions due to placebo treatment timing

IV.3. Mortality

Table 14. Mortality and placebo treatment-timing

	Under 75 Mortality	Under 75 Most Deprived	Under 75 Least Deprived	Mortality due to Asthma	Mortality Due to Respiratory Diseases	Mortality Over 75 years
Differences in Differences Model						
Closures X Post	0.006 (0.008)	-5.939 (7.397)	3.634 (5.096)	-0.029 (0.041)	0.007 0.023	0.012 0.010

Event Study						
Year -16	0.015 (0.020)					
Year -15	0.007 (0.015)	34.125*** (10.911)	-12.526 (7.705)			
Year -14	0.000 (0.009)	0.894 (7.202)	16.505*** (5.072)			
Year -13	-0.017 (0.012)	-11.318 (10.378)	-2.166 (5.958)			
Year -12	-0.005 (0.006)	-8.256 (6.940)	-2.471 (5.753)			
Year -11	-0.004 (0.006)	-6.352 (6.334)	1.324 (4.554)	-0.066 (0.128)		
Year -10	0.008* (0.005)	11.403* (6.308)	7.040* (4.248)	-0.211** (0.085)		
Year -9	-0.009 (0.006)	3.064 (4.668)	-3.985 (3.977)	0.084 (0.103)		
Year -8	0.005 (0.004)	-1.828 (4.866)	-2.141 (3.554)	-0.057 (0.097)		
Year -7	0.002 (0.005)	0.119 (4.220)	-0.337 (3.071)	0.051 (0.079)		
Year -6	0.009** (0.005)	2.104 (3.885)	2.068 (2.937)	-0.125 (0.090)		
Year -5	-0.006 (0.005)	1.632 (3.841)	-0.104 (2.525)	0.103 (0.071)		
Year -4	-0.006* (0.003)	0.308 (3.618)	-1.045 (2.521)	-0.082 (0.075)	-0.027 (0.038)	0.017 (0.032)
Year -3	-0.003 (0.003)	-4.804 (4.119)	0.027 (2.407)	0.046 (0.045)	0.021 (0.027)	-0.021 (0.022)
Year -2	0.003 (0.005)	-3.345 (3.589)	4.523 (2.889)	-0.005 (0.057)	0.014 (0.028)	-0.001 (0.015)
Year -1	0.003 (0.003)	4.218 (4.025)	-3.719 (2.802)	-0.054 (0.054)	-0.090** (0.042)	0.006 (0.018)
Year 0	0.001 (0.004)	0.785 (3.924)	0.228 (2.787)	-0.001 (0.047)	-0.006 (0.024)	0.009 (0.014)
Year 1	-0.003 (0.007)	-2.608 (6.777)	-5.651 (4.452)	-0.064 (0.057)	-0.006 (0.044)	0.005 (0.015)
Year 2	0.004 (0.010)	-15.947 (10.211)	-0.627 (6.712)	0.001 (0.066)	0.090 (0.069)	0.001 (0.015)
Year 3	0.001 (0.012)	-17.965 (11.544)	4.871 (6.132)	-0.023 (0.077)	0.030 (0.097)	0.012 (0.021)
Year 4	0.005 (0.014)	-4.871 (13.860)	12.273 (7.899)	-0.012 (0.086)	-0.056 (0.038)	0.050*** (0.013)
Year 5	-0.005 (0.014)	0.742 (15.274)	11.119 (9.693)	-0.090 (0.083)	-0.005 (0.046)	0.040 (0.035)

Year 6	0.013 (0.013)	-11.101 (26.501)	3.238 (14.721)	-0.053 (0.104)		
Year 7	0.049*** (0.014)	-5.741 (30.049)	9.465 (15.467)	0.013 (0.098)		
Year 8	0.020 (0.016)	-9.638 (21.204)	31.175* (11.486)	0.283*** (0.088)		
Year 9	0.024 (0.034)	23.579 (25.936)	31.446** (15.216)	-0.553*** (0.056)		
Year 10	0.027 (0.032)			-0.025 (0.061)		
Year 11	0.0521* (0.028)					
Obs.	951	780	780	556	124	126
Controls	Yes	Yes	Yes	Yes	Yes	Yes

*Note: This table displays result of staggered difference-in-difference model and event study. The sample is defined as mortality for the period 2013-2020 and the placebo treatment-timing for the coal plant closure for the period 2000-2022 in the local authority in England. Parentheses contain the se. Significance Levels: * = 10%, ** = 5%, *** = 1%*

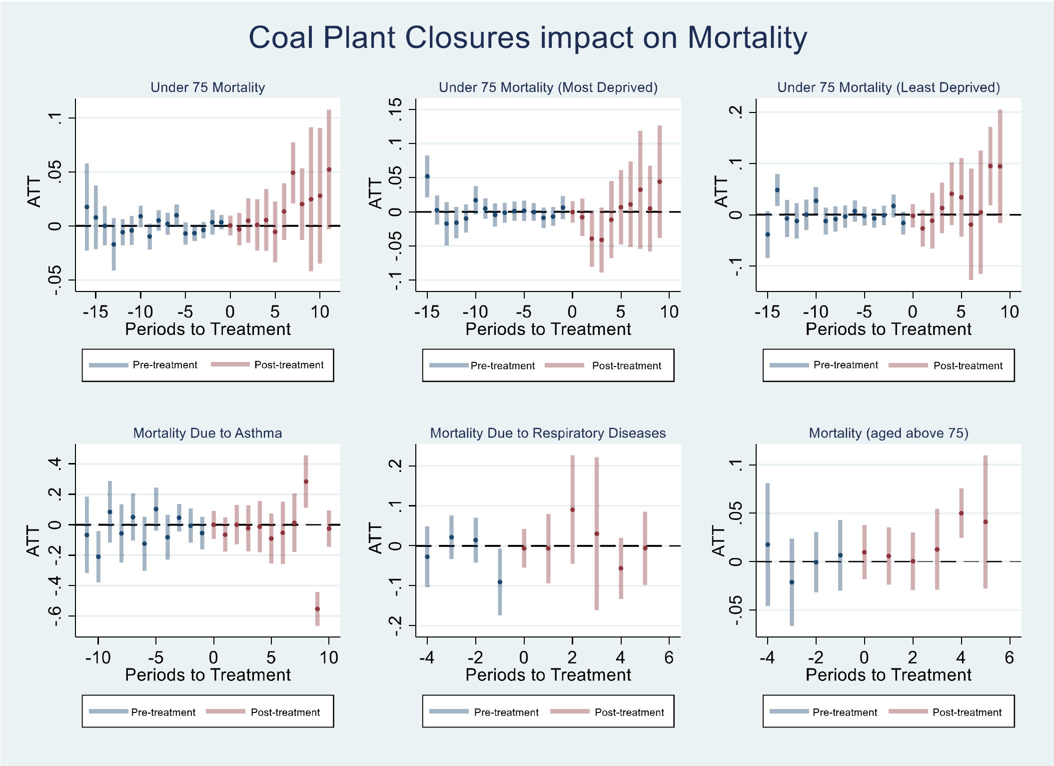

Figure 10. Event study of mortality due to placebo treatment timing

IV.5. Mental and Behavioral Diseases

Table 15. Mental Health and placebo treatment-timing

	Mortality Due to Diseases of Mental and Behavioural	Suicide Rate Male	Suicide Rate Female
Differences in Differences Model			

Closures X Post	0.043 (0.046)	-0.041 (0.046)	-0.036 (0.074)
Event Study			
Year -16		0.021 (0.050)	-0.274*** (0.090)
Year -15		-0.061 (0.051)	0.102 (0.079)
Year -14		0.030 (0.042)	0.117 (0.085)
Year -13		-0.023 (0.078)	-0.122* (0.066)
Year -12		0.002 (0.039)	-0.044 (0.100)
Year -11		0.012 (0.059)	0.146* (0.076)
Year -10		0.108 (0.079)	-0.036 (0.084)
Year -9		0.008 (0.068)	-0.041 (0.055)
Year -8		-0.099* (0.053)	-0.159* (0.088)
Year -7		-0.036 (0.059)	0.029 (0.099)
Year -6		0.014 (0.054)	0.072 (0.062)
Year -5		0.034 (0.051)	-0.084 (0.095)
Year -4	0.108 (0.161)	-0.025 (0.027)	-0.042 (0.064)
Year -3	-0.066 (0.091)	0.005 (0.025)	-0.079* (0.046)
Year -2	-0.035 (0.024)	-0.052 (0.043)	0.156*** (0.045)
Year -1	-0.018 (0.033)	0.046 (0.036)	-0.088 (0.067)
Year 0	0.031 (0.028)	-0.007 (0.031)	0.059 (0.036)
Year 1	0.098 (0.084)	0.041 (0.038)	0.063 (0.118)
Year 2	-0.087 (0.105)	-0.083 (0.075)	-0.083 (0.094)
Year 3	0.070 (0.072)	-0.057 (0.059)	-0.067 (0.136)
Year 4		-0.110* (0.059)	-0.305*** (0.095)

Year 5		-0.050 (0.087)	-0.411** (0.176)
Year 6		0.020 (0.086)	-0.290 (0.244)
Year 7		0.029 (0.158)	0.013 (0.165)
Year 8		-0.130 (0.103)	-0.011 (0.128)
Year 9		0.021 (0.172)	0.556*** (0.118)
Year 10		-0.329* (0.196)	0.092 (0.174)
Year 11		-0.262 (0.231)	-0.102 (0.287)
Year 12		-0.234 (0.179)	
Year 13		0.007 (0.102)	
Year 14		-0.075 (0.176)	
Obs.	116	593	413
Controls	Yes	Yes	Yes

*Note: This table displays result of staggered difference-in-difference model and event study. The sample is defined as mental health for the period 2001-2019 and for the placebo treatment-timing of the coal plant closures from 2000-2022 in the local authority in England. Parentheses contain the se. Significance Levels: * = 10%, ** = 5%, *** = 1%.*

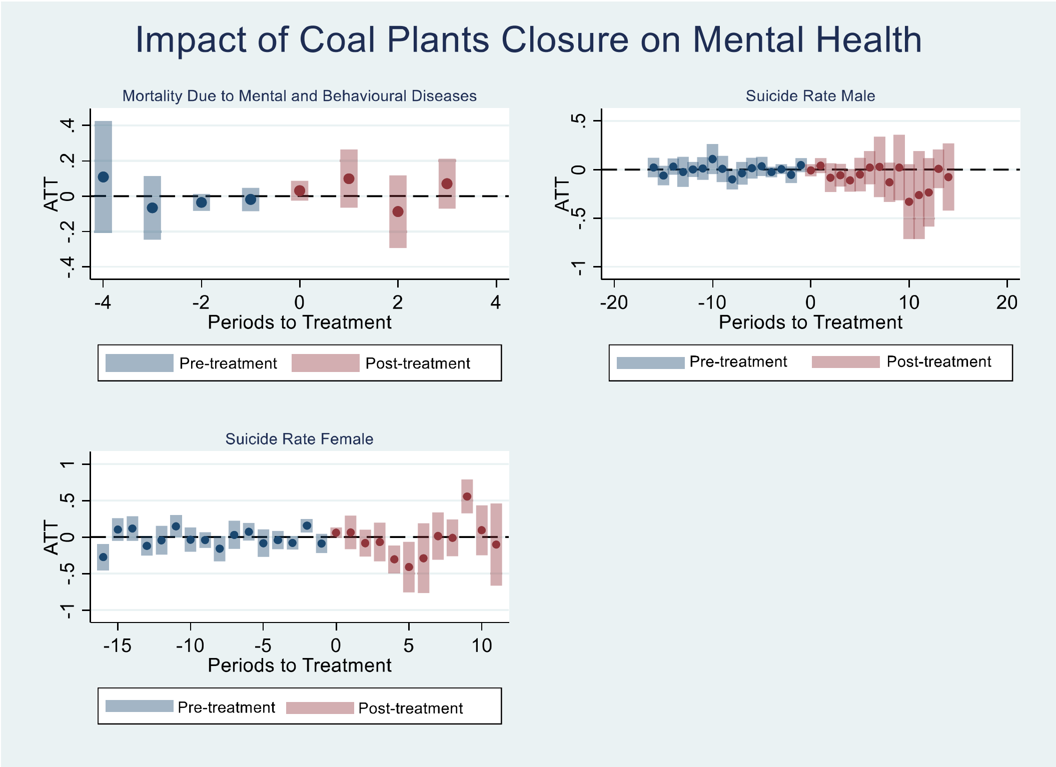

Figure 11. Event study of mental health due to placebo treatment-timing

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