An empirical analysis of the effectiveness of the regional greenhouse gas initiative policy on individual energy sources and mortality rates in the U.S

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Abstract

The aim of this paper is to examine the effectiveness of the US Regional Greenhouse Gas Initiative (RGGI), a cap-and-trade policy in 9 Eastern US states, on reducing the consumption of individual energy sources in the total electric power sector, mortality, and infant mortality rates. The importance stemming from the global need to reduce carbon dioxide emissions in the atmosphere to combat the disastrous effects of Climate Change. The research methodology used was a series of difference in differences (DID) quasi-experimental models over the period 2000-2020, for all 50 US states whereby the treatment in the model was the implementation of the RGGI policy in the selected states in 2008. The results from the analysis suggest significant reductions in overall energy consumption, coal, petroleum, and natural gas due to the implementation of the policy. Male crude mortality also significantly increased over the period whilst total crude infant mortality tested insignificant.

1. Introduction

The central and most important question that will be answered in my research paper is the effectiveness of the RGGI scheme on individual energy sources and mortality rates. The RGGI program which stands for the Regional Greenhouse Gas Initiative is a collective effort from 9 eastern States in the United States to reduce their carbon dioxide emissions. The desperate need to halt the process of climate change needs to be focussed on with the upmost of importance as it is arguably currently the most serious and damaging threat to humankind and if left on the current path could lead to irreversible changes to our way of life. The RGGI is the first cap-and-trade policy in the US with the aim to limit CO_2 emissions in the electric power sector. Specifically, the electric power sector, as electricity is predominantly derived from fossil fuels in the 9 participant States inevitably contributing to the production of harmful pollutants. The 9 States engaged in the initiative being: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont. The significance of these States' contributions is considerable since even though they only account for a fraction of the country in physical size, they account for 20% of the county's gross national product and 1/6 of the entire US population. The method behind the cap-and-trade system is for the governing RGGI committee comprising of representatives from each State, to set carbon dioxide emission caps for each year with the long-term aim to reduce the figure each annum. There are then allowance permits sold quarterly at auction whereby firms can purchase additional carbon dioxide emissions permits if they have already produced up to their limit. The program was established in 2005 but it was three years later in 2008 when the first auction for carbon emission permits began. The importance of the question cannot be understated as the effectiveness of the RGGI on the reduction of fossil fuel energy sources will aim future policy over the next decade to assist the US in fulfilling the pledge made at COP26, climate change summit in Glasgow 2021, to reduce carbon emissions and switch to clean energy. The analysis in this paper is crucial, since the US is the second largest energy producer in the world behind only China and so evidence of successful policy intervention could not only lead to decreased emissions in the country but could be a prompt for other mass producers to follow suit since there is evidence of its accomplishment.

The hypothesis being tested is that the implementation of the policy in the selected States has not led to a significant decrease in energy consumption when tested against the States that were not involved, whilst also testing for the effect of the policy on mortality and infant mortality rates. By breaking down the total electric power industry into individual energy components one can identify how the policy is affecting each individual source. The policy implications from the investigation could be highly substantial as it could potentially uncover an unequal effect on the various energy sources, whereby the program is significantly leading to a decrease of one pollutant and yet another could be unaffected or even increasing. It is more useful analysing the effectiveness of the policy in this way as opposed to simply a total change as you gather more data to guide judgment for the future policy decisions. The people that will benefit from this research is the committee of the policy allowing them to make more informed decisions in the future and potential changes to the current regime. You could argue a wider benefit from the investigation as there are currently 197 members of the United Nations Framework Convention on Climate Change and so any of those countries that are struggling to meet the agreed emission reduction targets could adopt similar cap-and-trade systems based on the results of this research. My contribution to the research topic is to provide very recent statistical updates on the program since the most recent literature surrounding the subject area finished in 2014 after only examining the first six years of the new policy. It is not uncommon that there is a lag period between the implementation of a new policy and the affects being seen because of its impact and so it is imperative that up-to-date analysis is being carried out. The data being used in the econometric estimation is panel data with 50 States as my cross-sectional ids over a 20-year period from 2000 to 2020. The state-level data on mortality, infant mortality and six individual energy sources will be the dependent variables regressed in separate difference-in-differences models with the independent variables being a dummy variable for whether the state implemented the policy in 2008, whilst also controlling for GDP. The limitation of the investigation is attempting to take into consideration what other possible factors could be affecting the level of energy consumption over the period. If there were any other notable shocks to the energy market that would have skewed the results in a particular direction, it must be controlled for. Therefore, seeing as fluctuations in gross domestic product have a significant relationship with energy consumption, it is subsequently controlled for and we can confidently attribute the success to the policy.

2. Literature Review

Since it began in 2008 there have been many academic papers around the subject of the RGGI examining various aspects of its effectiveness. A paper published in 2015 began to investigate the decline in greenhouse gas emissions in the RGGI States using econometric models (Murray & Maniloff, 2015). The study suggests that the decrease in the production of greenhouse gases comes not only from the policy in place but also other exogenous shocks to the economy, including the financial crisis in 2007, leading to an overall decrease in economic activity and the fact that the price of natural gas had fallen due to an increase in its availability. The results from the econometric model find that taking all the exogenous factors and the policy intervention into consideration, the power sector carbon dioxide emissions would be 60% higher in 2011 than the figure ended up being. When controlling for all other exogenous variables the results showed that the RGGI was the prevailing cause of the decline of emissions over the period. As mentioned in the introduction to this paper a limiting factor in this study is the difficulty in zeroing in on precisely how much of the decline was directly attributable to the initiative, however there is clear evidence of regional patterns of decline specific to the States who implemented the policy. The paper then suggests that the policy implications that have come from the analysis show room for improvement in the reduction of the electric power sector. This leads into the contribution of my research looking into which individual energy sources need specific policy targeting to bring overall carbon levels down in the industry. There is a brief mention of the possible switch to an increase in natural gas over coal, as it produces a significantly diminished amount of CO_2 emissions. However, it lacked clear statistical results to strengthen the argument.

With pressure mounting for nations all over the world at every climate change summit to meet their reduction targets it is important to not only look at one specific mandatory state-level policy, like the RGGI but to look at the country as a whole to identify the effectiveness of the introduction of the cap-and-trade system. A study in 2017 investigates the designs of various US polices in an attempt to uncover whether emission decreases at the state level are occurring due to the mandatory climate change polices, as opposed to smaller voluntary programs that are running simultaneously (Martin & Saikawa, 2017). The need to know which systems are more useful is imperative before even breaking down the results of the RGGI program, because if it were to be uncovered that a voluntary state policy, like the CAP, Climate Action Plan, or WCI, Western Climate Initiative, was more influential, it makes the analysis of the RGGI obsolete and so the other policy should be focused on. The results from the regression show that even though the CAP program included 34 States, a much bigger involvement than the 9 in the RGGI, it tested statistically insignificant in the reduction of emissions. It could be argued that the findings resulted in being insignificant because the plan focuses on adaptation as opposed to the mitigation of the damage caused by greenhouse gases. However, one could then question the purpose of the plan if no action is taken in a moment where time is of the essence. Another voluntary climate policy, WCI, also tested insignificant. On the other hand, the mandatory climate policy RGGI tested statistically significant in reducing carbon dioxide emissions in participant States. The results from the study suggest that the mandatory climate policy, RGGI, is effective at the state level in reducing energy consumption whilst voluntary polices were all insignificant.

The effect of the RGGI on the infant mortality rate in America is a very curious relationship as the main objective of the policy is to reduce CO_2 emissions, however if it were to create positive externalities including lowering the infant mortality rate, it would suggest another successful aspect of its implementation. A study in 2019 examined the impacts of the policy over the period 2003-2014, testing for the difference made 6 years before and after the policy began. Using a quasi-experimental difference-in-differences economic model to examine the difference in the pre-treatment group and the post-treatment group whilst still controlling for exogenous characteristics of the States, including GDP, population, median household income and number of hospitals (Lee & Park, 2018). The neonatal mortality rate (NMR) is defined as the number of children under the age of 28 days that die, and the infant mortality rate (IMF) is defined as the number of children under the age of 1 years that dies. The results from the investigation show an overall decrease in NMR by 0.13/1000 live births in the years post 2008 in states without the policy and a larger fall of 0.51/1000 live births for the states with the policy. There is significant evidence that there was an overall fall in infant mortalities in the six years after the RGGI was introduced. This research was a useful starting point to then examine how the relationship developed in the following 6 years after 2014.

There are other studies that focus on not only the infant mortality rates at the state level but more broadly at the wider benefits to children's health that has come from the RGGI program (Perera, et al., 2020). By aiming to reduce carbon dioxide emissions, it will inevitably create cleaner air which will lower the risk of associated diseases that arise from polluted air, predominantly being respiratory diseases. A recent paper published in 2020 explored the relationship between the decline in particulate matter (PM) and certain health problems, including term low birthweight (TLBW), asthma and autism spectrum disorder (ASD). The methodology of the paper used was a cost-benefit analysis approach whereby the health disorders were given an economic valuation based on the change in incidence rates caused by the change in PM, and then a cumulative change calculated by the incidence rates themselves along with the associated change in economic valuation. It was estimated that the financial health costs of all combined disorders in the study avoided, due to the existence of the RGGI program, between the years 2009-2014, added up to between $199.6 million to $358.2 million. Over the 5-year period this is already a significant amount saved, without even taking into account that the figure is most likely understated, as the long-term health benefits for many of the cases were not calculated in the figure.

The RGGI like any other policy implemented in a region can be successful in its purpose but will most likely come with limitations in certain areas. A potential limitation of the policy that was brought up in a study was the potential emission leakages that could occur through the introduction of price caps. In this instance emission 'leaks' refers to a situation whereby an increase in carbon emission occurs in one region due to a strict cap in another. The cap-and-trade emission system can be effective when the regulation is done correctly. A paper in 2008 ran simulations on the future potential results of the policy just as it had begun and concluded that if the permits of carbon dioxide allowances that were sold at auction were too large, the environmental damage that would be done would lead to the policy being counterproductive and ineffective, whilst resulting in emission leakages (Sue & Kolodziej, 2008). Another caveat being consumers within RGGI states were allowed to import electricity from non-RGGI States who are not restricted.

Following on from the potential limitations that academics foresaw when the policy was new, five years later, with the data collected, there are both positive and negative aspects of how the limitations turned out (Ramseur, 2013). The unfortunate timing of the beginning of the policy and the 2007/08 financial crisis meant that even though firms were not interested in purchasing imported electricity from neighbouring States, it was most likely not because they were prioritizing internal emission reduction but suffering financially from the exogenous shock of the 'Great Recession' which lasted for a year and a half ending in June 2009. A result which wasn't predicted, with regards to the quarterly run auctions, was that profits that had been made and distributed to all RGGI States had been used to fund the ongoing pursuit of sustainable renewable sources of energy which can only lead to positive developments in the long-term interest of reducing carbon emissions. Nevertheless, criticism did arise as some states began to use the profits gained at auction as an additional revenue source to deal with budget deficit issues. In terms of future policy as the situation becomes more time sensitive there may be a need to enforce stricter proposals on where the profit from the auctions is allocated.

When analysing the effects of the RGGI on energy sources that produce greenhouse gases, it can be very beneficial to examine how renewable energy is simultaneously affected, seeing as the long-run implications of making large strides in the sector will make the need to consume fossil fuel energy obsolete. The future of the energy market is the transition from fossil fuels to clean renewable energy sources. Since the increasing urgency of the Climate Change summits, more and more importance has been placed upon world governments to prioritise the movement away from fossil fuel production. A very recent report, published in 2022, assessed the changes in renewable energy innovation in the Fortune 500 companies in the US, using the difference-in-differences methodology to test the impact of the RGGI policy after it was imposed in 2008 (Rahman, et al., 2022). After preliminary testing it was found that the coefficient of the policy interaction term was negative and statistically significant at the 1% confidence level, suggesting that the RGGI caused firms to file less patents in the renewable energy sector. This is a surprising revelation as you would expect that more firms would concentrate on the future of the market, being renewable sources, as the carbon emission cap is lowered each year. This could suggest flaws in the current auction system as the market equilibrium price could possibly not be high enough to slowly disincentivise more firms each year to buy less and less. Another potential reason for the lack of innovation is that even though clean energy is the accepted future direction of the energy market, there is a large amount of uncertainty associated with the lack of academic studies and individual researchers. There is a much smaller database of knowledge for spill overs to occur, leading to companies being much more hesitant with investment.

When examining the effects of the RGGI on individual energy sources in this paper, the main searching point is to find conclusive evidence that one source is having a significantly greater effect than the others, allowing you to find scope to positively guide future policy and reduce overall consumption even more. There are many mentions of the switch from coal to natural gas in the electricity power market since the shale gas boom. A paper in 2015 attributes the switch away from coal as a significant factor in the success of the RGGI program, however the study does not consider the other energy sources producing significant quantities of carbon dioxide emissions, showing the importance of the evidence found in this paper (M.Kim &

T.Kim, 2015). By looking at all the individual sources in the total electric power industry you can make a clear judgment on which is being affected the most and crucially the effect they have on each other, leaving us in a fortunate position looking at 14 years' worth of state level data to inform on the most beneficial route for future policy.

3. Economic Theory and Econometric model

3.1 Economic Theory

Economic theory on the subject matter would suggest that a cap-and-trade policy will reduce carbon dioxide emissions in the region coming from a reduction in consumption of pollutant energy sources, seen in past literature. Carbon tax policies and emission trade systems are at the forefront of the global mission to reduce the increasingly important issue of climate change. The need for government intervention in the market stems from the market failure associated with resolving climate change problems. Climate change occurring primarily because of the consumption of carbon intensive energy sources, is a public bad and is globally non-rival and non-excludable, meaning that everyone in the world will be exposed to the negative effects that will potentially arise from it and no one can exclude themselves from its harm. The negative externalities produced from the consumption of carbon intensive energy sources are both global and long term which can have disastrous consequences. Policy makers that are more concerned about increasing GDP in the short term to potentially stay in power, will likely not take into account the negative externalities placed onto the next generation which could be irreversible. The existence of the free rider situation whereby countries have an incentive to allow other nations to reduce their emission rates whilst they stand back producing at the same level as normal is another associated market failure, however the frequent climate change summits attempt to mitigate that issue. The health risks associated with increasing levels of carbon dioxide in the atmosphere are widely known and accepted in various literature. A recent study in 2019 examines not only the physical illness that can occur predominantly to the respiratory health of an individual but also significant damage to cognitive functions when exposed to increased levels of CO_2 emissions in the atmosphere (Jacobson, et al., 2019). Consequently, the theory suggests that the implementation of a policy like the RGGI will lead to a reduction in both infant mortality and mortality rates, however it is likely to take longer to see the effect in mortality rates as opposed to the reduction in consumption of fossil fuels. Infant mortality rates could see a faster impact seeing as it is arguably the most sensitive variable associated with health (Weldearegawi, et al., 2015). This is because in an infant's earliest years they are at their most vulnerable to illnesses which can often be fatal due to the underdevelopment of their immune system, however illness in grown adults may take a much longer period to be fatal if that is to be the case. There will be future concerns when testing the long-term effectiveness of carbon tax policies on mortality due to the recent COVID-19 pandemic. An exogenous shock of that proportion which has caused a lowered life expectancy in the US, the largest fall since World War 2, will cause considerable doubt when investigations conclude how the figures are attributed to the RGGI policy or any other polices (Santhanam, 2021). Seeing as this research ends in 2020, the data will be unaffected on the whole.

3.2 Econometric Model

The methodology of the investigation is the set of statistical regression analysis on a panel data set at the State level in the United States of America. The cross-sectional ids being the 50 individual State regions in the nation over a 20-year period, 2000-2020. The economic model or framework being applied in this research is the Difference-in-Differences (DID) approach. The DID framework is quasi-experimental design approach used to test the differences in variables after a specific treatment event has occurred. It allows one to examine the affects before and after the exogenous treatment event happens. Therefore, in the analysis there will be a control group which was not affected by the exogenous event, which in this case is the implementation of the RGGI policy, and a treatment group which was affected by the RGGI policy. The treatment group are the 9 US States involved in the policy and the control group contains the remaining 41 States. The economic model used is seen as follows:

$$y_{st} = \beta_0 + \beta_1 post_{st} + \beta_2 trmt_{st} + (\gamma post_{st} * trmt_{st}) + GDP_{st} + \alpha_s + \mu_{st}$$

The model (above) illustrates the framework used in the regression analysis, whereby the dependent variable,y_{st}, being what will change in each specific regression. The statistical computer software used to analyse the data and run regressions on the model is Stata. A potential issue in the model regarding the unobserved heterogeneity, α_s, and the idiosyncratic error μ_{st}, is that the covariance of the unobserved heterogeneity and one or more of the independent variables is not equal to zero $COV(\alpha_s, X_{st}) \neq 0$,which is a violation of the OLS estimates in order for it to be consistent. Using Stata, you can use the built-in features to run the regressions with either fixed effects or random effects. Before choosing which model estimate to use one can run the Hausman test to guide the decision. The specification of the test is that null hypothesis assumes that the random effects model should be used, whilst the alternative hypothesis is that the fixed effects estimate should be used. Through the results of the Hausman test shown in the results section, we use both the fixed effects and random effects estimators in various regressions to remove the issues of unobserved heterogeneity. There are multiple regressions in the analysis with a different dependent variable for each logarithmic transformation of energy sources: coal, petroleum, natural gas, hydroelectric, wood derived fuel, nuclear, and wind, also infant mortality, and mortality rates. As well as both infant mortality and morality rates being divided by gender to result in a total, male and female variable. In this way not only can overall health be examined but individual effects by gender can be investigated possibly leading to a significant implication. The variable ‘post’ representing the post-treatment group, equals a dummy variable that is equal to 1 for the States where the RGGI policy was implemented after 2008. The variable ‘trmt’ represents the treatment group and is therefore a dummy variable equal to 1 for RGGI States for all years highlighting their involvement in the treatment. The coefficient β_2, will control for unobserved time constant differences between the control group and the treatment group whilst the coefficient β_1, controls for all unobserved changes that will affect both the control and treatment group. The key coefficient in the analysis is the gamma coefficient γ, in front of the interaction term of the post-treatment and treatment group variables. The gamma coefficient represents the effect of the treatment on the average outcome of the dependent variable and can be defined as the difference between a series of differences in the intercepts, $\beta_0 + \beta_1 + \beta_2$, hence model difference-in-differences. The variable GDP_{st} is included in all regressions as it controls for observable differences within and between groups, subscript ‘st’ describing the nature of the panel data with cross sectional id being state and time in years. Gross domestic product must be controlled for in the model as it can influence energy consumption and mortality rates. States with higher GDP figures tend to have higher energy consumption as it can afford to facilitate more factories with higher output and mortality rates tend to be lower in regions of higher affluence.

$$Logcoal_{st} = \beta_0 + \beta_1 post_{st} + \beta_2 trmt_{st} + (\gamma post_{st} * trmt_{st}) + GDP_{st} + \epsilon_{st}, fe$$

The fixed effects model (above) is an example of the framework used whereby gamma represents the effect of the RGGI policy on the average outcome of log coal consumption.

4. Data

4.1 Regional Greenhouse Gas Initiative

The information on the cap-and-trade system in the research, the RGGI policy, was found on the official RGGI website. All necessary material and background information was found here, including an overview of the policy, the aims, the participant States, and current news updates on activity related to it. The variable used to recognise whether the State has implemented the policy is a dummy variable, 'RGGI' which is equal to 1 for States involved after the year 2008 and equal to 0 for the States not involved for all years.

4.2 Energy Sources of the Electric Power Sector

The data used in the research of this topic was found in a variety of reliable databases. Initially, the data on energy consumption was taken from the EIA, US Energy Information Administration website, which is a statistical agency in the department of energy responsible for providing reliable and accurate energy data for forecasting, leading to future policy decisions. The data source used was the Net generation by State by Type of producer by Energy, annually produced over all 50 States for all years. In its raw form the data stretched from 1990-2020 and contained data points for each individual type of producer in the total electric power sector. Via manipulation of the data in the Microsoft Excel software package, the relevant period of this investigation, 2000-2020, was focussed on. The 'type of producer' was then aggregated to the total electric power sector, to have an overview of the market. The data measured the electrical output consumption for each energy source in megawatt hours. The focus on this research was the effects on individual energy types and so the subsection 'type of energy' was also manipulated as it contained specific energy sources that were not appropriate but also 7 relevant sources. Of the chosen energy sources, 5 were fuels that when consumed produce harmful CO_2 emissions namely: coal, petroleum, natural gas, hydroelectric fuel, and wood derived fuel, whilst the other 2, nuclear and wind, do not directly produce emissions when consumed to generate electricity. By examining the effects of the RGGI on both pollutant and non-pollutant energy sources, one can analyse the success of the policy in reducing the fossil fuel consumption and the subsequent effect of a potential rise in renewable energy sources. The total for all energy source consumption was also an included variable. The logarithmic transformation was taken for all the energy source variables to improve the fit of the model and to make future interpretation simpler as it now follows a more normal distribution. There are a few limitations to the data, as even though for the most part the majority of variables are complete for every year and state with a very insignificant amount of missing data, there are limitations for wood derived fuel, nuclear and wind consumption which has a significantly large amount of missing data entries, seen in the summary statistics.

4.3 Mortality and Infant Mortality

The relevant medical data for the mortality and infant mortality rates in the US were taken from the CDC, Centers for Disease Control and Prevention website. Using the WONDER system on the website which is the CDC internet database that is available for public consumption. The specific criteria were inputted into the system to obtain the appropriate data. The database allows one to search by state and then by year for all kinds of mortality rates, dependent on age, gender, race, cause of death and other options. Refining the selection to the 50 States over the 20-year period and then initially by mortality for all ages for both genders, the data is generated. The population, mortality rate (MR) and crude mortality rate in each year for each State is generated in a table ready to be extracted. The mortality rate is defined as the number of deaths in a certain area over a period, whereas the crude mortality rate is the number of deaths in a certain area over a period as a proportion of the population in the area given per

100,000 people in this case. The crude mortality rate is particularly useful in the analysis as population size is controlled for and so one can be confident in the fact that the varying population sizes in States is not influencing the effect of the RGGI on mortality rates. The mortality rate can then be separated by gender resulting in a total crude mortality rate variable, a male crude mortality rate and female crude morality rate. By altering the age tab to infant age groups this will once again generate infant mortality (IM) rates by State and year, as a total, for men and women. Mortality data for all 3 subsections was in full, whilst infant mortality was incomplete, however only very marginally. Hence the limitations of the data are little to none.

4.4 Gross Domestic Product

Data on gross domestic product, GDP in the US at the State level was found on the Bureau of Economic Analysis website. The data available for all 50 States over the period, 2000-2020, in the statistical format of real GDP millions of chained 2012 dollars. Chained dollars is a method of adjusting for inflation over a period using 2012 as the base year to be able to compare values of time. The unit of measure is then the percentage change from the preceding period. Once again, the limitations to the data are minimal seeing as the data is complete and from an accurate and reliable database.

For the data to be fully complete there should be 1050 observations per variable and seen from the summary statistics the majority are extremely close to the mark apart from the logarithmic transformation of wood derived fuel, nuclear and wind, which is incomplete.

Summary Statistics (3d.p)					
Variable	**Observations**	**Mean**	**Std. dev.**	**Min**	**Max**
Statefip	1050	29.32	15.631	1	56
Year	1050	2010	6.058	2000	2020
Mortality Rate	1,050	51719.78	51549.38	2914	319808
Infant Mortality Rate	1,050	503.123	526.0583	15	2944
Mortality CR Total	1,050	869.528	138.294	462.8	1462.7
Mortality CR Men	1,050	888.061	146.706	515.4	1569.6
Mortality CR Women	1,050	851.312	136.334	406.2	1357.7
Infant Mortality CR Total	1,047	6.421	1.358	3.1	11.3
Infant Mortality CR Men	1,026	7.068	1.551	3.5	13.2
Infant Mortality CR Women	1,009	5.848	1.261	3.3	9.8
GDP	1,050	3.738	3.475	-15.3	24.6
Treatment	1,050	.18	.3844	0	1
Log total energy consumption	1,050	17.784	1.014	14.463	19.996
Log Coal	1,014	16.276	2.752	-4.605	18.877
Log Petroleum	1,048	12.034	2.207	.0100	17.519
Log natural gas	1,031	15.488	2.378	-4.605	19.359

Log hydroelectric	1,008	14.149	1.881	7.663	18.335
Log wood	756	11.640	5.071	-4.605	15.643
Log wind	561	13.510	2.464	-4.605	18.342
Log nuclear	644	16.769	0.786	14.594	18.423

5. Interpretation and Analysis of Results

5.1 Carbon-intensive energy sources results

The key results from my analysis come from examining the $\gamma(gamma)$ coefficient in each regression to examine the difference-in-differences effects of the treatment on average outcome for the dependent variable. Initially assessing the results of the DID effects on individual energy sources as seen in figure 1. The logarithmic transformation of total energy consumption in the total electricity power sector had a coefficient of -0.189 and was statistically significant at the 10%, 5% and 1% level. Seeing as the regression for energy sources is log-linear with the independent variable being a binary dummy for the RGGI policy the coefficient is interpreted using the formula, $(e^{\beta} - 1) \times 100$. Meaning the effect of the RGGI on the total energy consumption was a -17.22%. The sign in front of the coefficient being negative suggests a success of the policy in reducing energy consumption and therefore carbon emissions, however only a 17% fall over a 14-year period since it began in 2008 can lead to an argument for its ineffectiveness. Examining the breakdown of individual energy sources, the coefficient for log coal is seen to be -1.79 whilst having a p-value equal to 0 suggesting it is statistically significant at all levels. Substituting in the coefficient for log coal, $(e^{-1.79} - 1) \times 100$ the model suggests that the implementation of the policy has caused the consumption of coal to fall by 83.30%. The consumption of coal as a use of energy production is the most carbon intensive method as opposed to the other sources in the dataset, leading to feasible claims that it is the most important variable to analyse with the main aim being to reduce CO_2 emission rates. The significantly large decrease of 83.30% in coal consumption bodes well for the success of the policy. The results for log petroleum were very similar being statistically significant with p-value < 0.05 with a coefficient of -1.13. The coefficient translates to a decrease of 67.70% which is smaller than the decreases in coal but still a large achievement of the policy. The consumption of wood derived fossil fuels was statistically insignificant suggesting that the data is not sufficient to make a conclusion. This could be accounted for due to the limited availability of the data. In contrast, natural gas returned statistically significant results at all levels with a -0.59 coefficient. The negative coefficient shows that another energy source has seen a decrease in consumption due to the RGGI policy with an average treatment effect of -44.35%. Hydroelectric consumption was only significant at the 10% level with a minimal average treatment effect of 7.78%.

DID effects of the policy treatment on average outcome for each dependent variable models (3d.p) – Figure **1**

Dependent Variable	Policy Treatment γ coefficient	Standard errors	Test Statistic	P-value	No. of Observations
Log coal	-1.790***	0.190	-9.43	0.0000	1014
Log petroleum	-1.130***	0.125	-9.01	0.0000	1048
Log natural gas	-1.112***	0.135	-8.21	0.0000	1031
Log total energy consumption	-0.189***	0.0211	-8.99	0.0000	1050
Log hydroelectric	-0.0810*	0.0438	-1.85	0.065	1008
Log wood	0.211	0.371	0.57	0.570	756

1% significance level *** - 5% significance level ** - 10% significance level *

5.2 Non-fossil fuel Energy sources results

The results of the effectiveness of the RGGI on non-carbon-intensive energy sources, wind and nuclear, figure 2, were constrained due to the limitation of data availability, nevertheless the regression analysis found the log of nuclear and wind consumption to be insignificant at all levels. The economic theory would suggest that at the same time as the decline in carbon intensive energy source use, coal, petroleum, and natural gas, it would then lead to companies turning to other sources that do not reinforce the carbon emission crisis. This was not seen in the results as the energy sources producing the least pollutant emissions saw no significant changes in consumption.

DID effects of the policy treatment on average outcome for each dependent variable models (3d.p) – Figure **2**

Dependent Variable	Policy Treatment coefficient γ	Standard errors	Test Statistic	P-value	No. of Observations
Log wind	-0.0973	0.548	0.18	0.859	561
Log nuclear	0.033	0.0264	1.26	0.207	644

1% significance level *** - 5% significance level ** - 10% significance level *

5.3 Mortality and Infant Mortality results

Seen by the results displayed in figure 3, total crude mortality rates resulted in being statistically insignificant with a p-value of 0.593 being far greater than 0.05. The results for total mortality rates were not what theory would suggest. However, the breakdown of the total crude mortality rate by gender showed that for men the results were significant at the 10% level, whilst the rates for women were insignificant with a large p-value of 0.37. The linear-linear nature of the model means the interpretation of the coefficient for men's rates is that there is an increase in men's crude rate mortality figures by 9.05 per 100,000 people for a unit change in the RGGI policy. An increase in the crude mortality rate goes against the theory for the effect of the RGGI but also contradicts the general falling trend in death rate accompanied by increased life expectancy figures in the US. As a comparison the total mortality rate is also significant at all levels but has an opposite negative coefficient of -4971.88, suggesting a fall in the death rate by 4971.88 people for a unit change in the RGGI.

The regression analysis on crude infant mortality proved to be insignificant for total rates and then subsequently for both male and female rates as well. Total infant mortality was significant at the 10% level with a positive coefficient of 22.68, suggesting an unexpected increase in the death rate by 22.68 infants for a unit change in the RGGI.

DID effects of the policy treatment on average outcome for each dependent variable models (3d.p) – Figure **3**

Dependent Variable	**Policy Treatment γ coefficient**	**Standard errors**	**Test Statistic**	**P-value**	**No. of Observations**
Mortality Rate	-4971.88***	861.167	-5.77	0.0000	1050
Infant Mortality Rate	22.680*	13.216	1.72	0.086	1050
Mortality CR Total	2.244	4.194	0.54	0.593	1050
Mortality CR Men	9.047*	4.715	1.92	0.055	1050
Mortality CR Women	-3.690	4.141	-0.89	0.373	1050
Infant Mortality CR Total	0.0356	0.0914	0.39	0.697	1047
Infant Mortality CR Men	0.00455	0.1220	0.04	0.970	1026
Infant Mortality CR Women	0.101	0.112	0.90	0.369	1009

1% significance level *** - 5% significance level ** - 10% significance level *

5.4 Hausman test results

The Hausman test which is referred to as the test for model misspecification can be run through the software Stata to help make the decision on whether each regression model is run using fixed effects (FE) estimates or random effects (RE). Each regression using different dependent variables was run using both FE and RE estimates and then the Hausman test was conducted, the results seen in figure 4. When the p-value is less than 0.05, we reject the null hypothesis at the 5% level and assume the regression with fixed effects. Seen from the table, all crude mortality and crude infant mortality regressions used fixed effects estimates along with natural gas, hydroelectric, wood derived fuel and coal. The other dependent variables investigated in the research, total energy consumption, petroleum, wind, and nuclear consumption failed to reject the null hypothesis and so used the random effects estimator.

Hausman Test Results for all models – Figure **4**

Dependent Variable	**Chi-Sq Statistic**	**P-value**	**Type of Regression Model**
Mortality CR Total	13.86	0.0002	**Fixed** Effects
Mortality CR Men	13.90	0.0002	**Fixed** Effects
Mortality CR Women	12.84	0.0003	**Fixed** Effects
Infant Mortality CR Total	10.94	0.0042	**Fixed** Effects
Infant Mortality CR Men	10.97	0.0269	**Fixed** Effects
Infant Mortality CR Women	14.29	0.0266	**Fixed** Effects
Log coal	95.96	0.0000	**Fixed** Effects
Log petroleum	5.43	0.1426	**Random** Effects
Log natural gas	98.90	0.0000	**Fixed** Effects
Log total energy consumption	0.68	0.4089	**Random** Effects
Log hydroelectric	4.65	0.0310	**Fixed** Effects
Log wood	494.60	0.0000	**Fixed** Effects
Log nuclear	3.85	0.2785	**Random** Effects
Log wind	18.62	0.4153	**Random** Effects

5.5 Model variation test for Robustness

Robustness checks are run in empirical investigations to test how the important coefficients in the analysis vary when a certain aspect of the model is changed. The type of robustness check run in this paper is called a model variation test, whereby there is change in the sample of the baseline model. The sample of 50 cross sectional id States is restricted to the 9 RGGI States and 10 Eastern States bordering the RGGI regions, totalling 19 States. The 10 non-RGGI States in the model being: Indiana, Kentucky, Michigan, New Jersey, North Carolina, Ohio, Tennessee, Virginia, West Virginia, and Pennsylvania. The same difference-in-differences econometric model that was applied to the baseline model is also used for the new restricted sample. The results seen in figure 5 show total crude mortality rates go from insignificant in the baseline model to significant in the restricted model. Total crude infant mortality remains statistically insignificant. With regards to energy sources, log coal remains significant at all levels, whilst the sign of the coefficient remains negative, its value has increased from -1.79 to -1.63, suggesting a -80.4% average change in coal consumption due to the RGGI program, which is very close to the baseline model. Overall total energy consumption is still significant with a p-value of 0.038 being lower than the necessary 0.05 to conclude significance however, the coefficient has decreased to -0.071 from -0.190. Log petroleum and natural gas both remained significant with negative coefficients however whilst the coefficient value for petroleum stayed very similar, natural gas saw a change from -0.59 to -1.11 which is the equivalent of the reduction increasing from 44.57% to 67.04%. The log of wood derived fuels, wind and nuclear consumption all remained insignificant at all levels. Whilst hydroelectric consumption differed from the baseline model and became insignificant at all levels in the restricted model. The variation of results in some of the regressions is a limitation of the analysis as the differences in significance and coefficients found in the robustness test model leads to increased uncertainty in the baseline models calculated estimates.

Model variation test for Robustness (restricted sample size of 19 States Eastern States) – Figure **5**

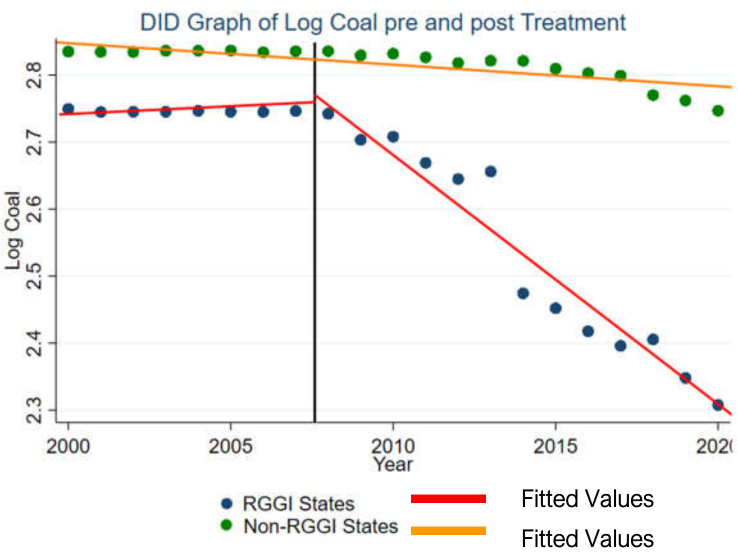
Dependent Variable	**Policy Treatment γ coefficient**	**Standard errors**	**Test Statistic**	**P-value**	**No. of Observations**
Log coal	-1.635***	0.368	-4.44	0.0000	363
Log petroleum	-1.379***	0.1399	-9.86	0.0000	399
Log natural gas	-1.112***	0.135	-8.21	0.0000	399
Log total energy consumption	-0.0709***	0.341	-2.08	0.038	399
Log hydroelectric	-0.00165	0.0464	-0.04	0.972	378
Log wood	0.426	0.335	1.27	0.205	308
Log wind	-0.150	0.886	-0.17	0.866	213
Log nuclear	-0.0387	0.0267	-1.45	0.147	266
Mortality CR Total	-11.303***	5.461	-2.07	0.039	399
Mortality CR Men	-8.313	6.248	-1.33	0.184	399
Mortality CR Women	-13.836***	5.042	-2.74	0.006	399

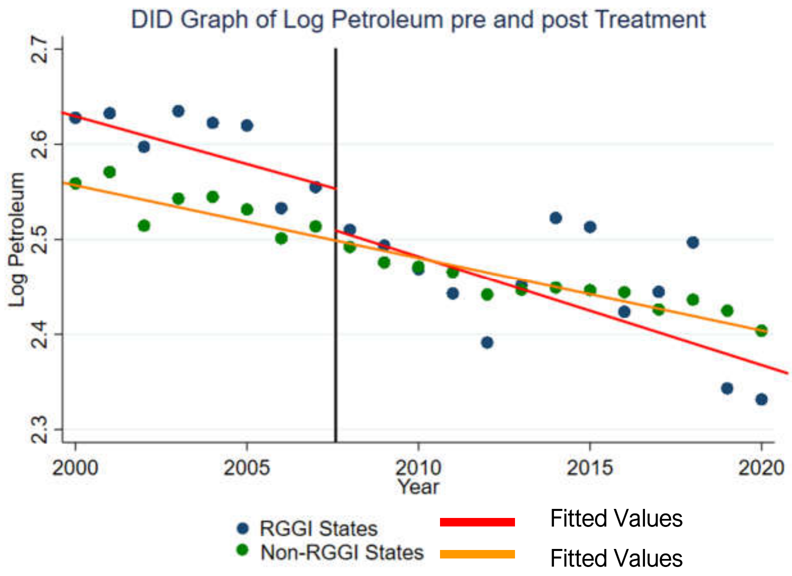
Infant Mortality CR Total	0.0771	0.111	0.70	0.486	396
Infant Mortality CR Men	0.0739	0.147	0.50	0.616	381
Infant Mortality CR Women	0.124	0.129	0.96	0.338	373

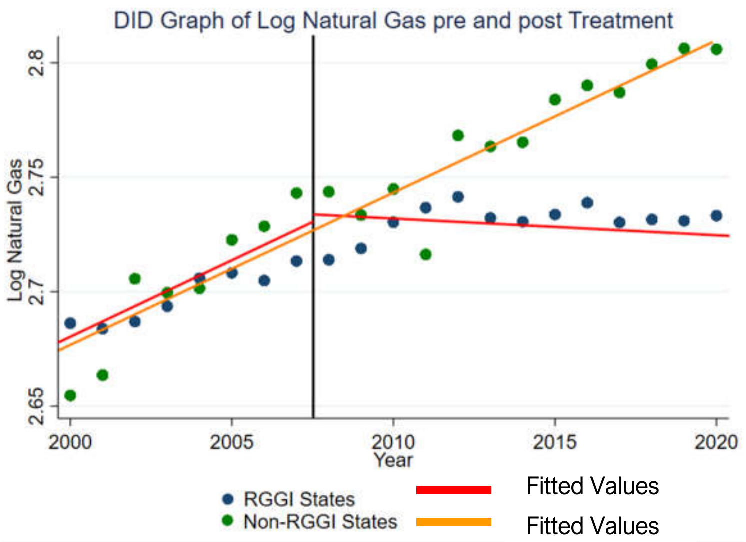
1% significance level *** - 5% significance level ** - 10% significance level *

5.6 Graphical Representation

The graphs below, constructed through the software Stata, for log coal, petroleum, and natural gas show visually the effects of the implementation of the RGGI in 2008 using the difference-in-differences framework. The blue dots representing the aggregate values of the RGGI states, and the green the non-RGGI States. The red line representing the fitted values of the RGGI states and the orange line the fitted values of the non-RGGI states. It can be found for all 3 graphs that the gradient of the fitted line after the policy came into effect in 2008 was steeper for RGGI States, suggesting that the decline was more significant for States executing the policy. Log coal indicates the largest difference in the gradient of the fitted values, as consumption plummets after 2008 for RGGI whilst the decline of the non-RGGI was very gradual. The most surprising was the consumption of log natural gas as the fitted values for non-RGGI consumption suggests a strong positive correlation, whilst RGGI saw a slight negative gradient from 2008-2020. Visually, log petroleum suggests the smallest difference in negative gradients for both fitted values which is plausible as it had the smallest percentage change over the period of the three energy sources. Nevertheless, the gradient of the values for RGGI states was again steeper than the non-RGGI states since 2008.







5.7 Discussion of results

The results on the average effect of the treatment on individual energy sources proved to be very positive when examining the effectiveness of the program. The significance of the decreases in total energy, coal, petroleum, and natural gas consumption at the 5% level since the implementation of the RGGI in 2008 showcases the success of the policy in its attempts to reduce carbon dioxide emissions. It is particularly noteworthy that the three energy sources that proved to have significantly fallen the most in consumption over the period are the largest producers of harmful pollutants, with the largest decrease being in coal consumption of 83.30%. An explanation as to why natural gas fell at a smaller rate could be explained by the fact that the combustion of natural gas produces around 30% less CO_2 emissions than petroleum and 45% less than coal, suggesting that it was more beneficial for large firms to focus on methods to reduce both coal and petroleum consumption as to achieve significantly reduced CO_2 emissions to meet the specified quotas. The insignificance of the RGGI program for both hydroelectric power and wood derived fuel consumption at the 5% is a possible flaw of the current policy and has the potential to be a future target for policy makers. Alternatively, the lack of effect on hydroelectric consumption could be explained by the fact it contributes 793 grams of carbon dioxide equivalent per kilowatt-hour of electricity less than coal (Smoot, 2022). So, when examining the effectiveness of the RGGI program one could argue that the decrease of coal, petroleum and natural gas consumption should be prioritized over other sources and therefore seen from the results, current policy has been very effective.

Non-carbon intensive energy sources are undoubtedly the future of the energy market as nations including the US slowly attempt to diminish their consumption of pollutant energy sources. Therefore, the effect of the RGGI on renewable energy could be argued to be just as important as the effect on fossil fuel consumption as firms need a long-term exit plan that does not grind production to a halt. The insignificance of nuclear and wind consumption in the total electric power market in the results could then pose a serious issue with the current policy. Within published literature the importance of maximising the potential of offshore wind energy in not only the US but in major European economies as well is paramount (Kumar, et al., 2014). It has been stated by the "US Department of Energy that the potential generating power of offshore wind energy in US areas with less than 100ft of water is equal to the total generating capacity of the current US electric system." This shows just how crucial the development and implementation of the use of wind energy sources in the total electric power market will be to the US. The RGGI committee could consider adding stricter constraints on where future profits that are collected from the quarterly permit auctions are spent on. With a push towards 100% reinvestment into renewable energy projects for the future. The results of nuclear consumption being insignificant as well, at all levels, is reason for concern with current policy, as it is a clean energy source which does not directly produce any harmful greenhouse gases into the atmosphere (EIA, 2021). On the other hand, unlike wind energy there are unfortunately many disadvantages to nuclear energy making it not a viable choice for the future of a completely clean energy market. Radioactive material and waste that is produced from consumption causes difficulties in its disposability for government, financially and ethically. This could explain as to why firms do not see any point in investing capital and funds into the advancement of nuclear energy technology and therefore why it resulted in insignificant change over the period. Nevertheless, it must also be understood that scientific advancement in the field may change the argument as the potential for nuclear fusion in the next few decades would increase the energy output whilst also drastically diminishing the toxic waste products produced in the process.

The theory for the health impacts of the RGGI suggested that both mortality and infant mortality rates should decrease in the regions where the policy was implemented given that the program is in fact effective in reducing carbon emission rates. On the basis that there is strong merit for the argument that from the results the policy was successful in reducing pollutant emissions, the results for the total crude mortality rate contradict what was expected to be seen in the findings. The coefficient being positive for male crude mortality rates suggest an increase in the death rate of 9.05 per 100,000 people for every unit change in the policy. On the other hand, it could also be argued that the increase in the crude mortality rate would have been expected since when testing the crude figures, the population size of the region is taken into account. It is known that many developed nations have been experiencing increased crude mortality rates in the last decade owing to the high proportion of older people in the population. It is noteworthy that only male rates were significant, and women's rates were not which could possibly suggest a disparity in the number of male and female workers in the energy sector. Although as the total energy consumption fell, it would suggest a lower death rate if the energy sector labour force was majority male dominated but since we found an increase in the male crude mortality rate, that could lead to further investigations being necessary into what could have caused that. A limitation of the analysis is that the 14-year post treatment period may also not be a long enough time frame to confidently examine the effects of the program on the crude mortality rates. The adverse health effects, respiratory problems, that come from pollutant gases in the atmosphere may have already taken its toll on individuals' years prior to 2008 leading to their current deaths.

The results for total crude infant mortality contradict not only economic theory but also past literature. Past literature running a similar quasi-experimental (Lee, Park 2019) study on infant mortality after the first 6 years of the RGGI, found a significant reduction in the infant mortality rate after the policy was introduced, however not only was crude infant mortality insignificant in this investigation but when testing infant mortality at the State level it proved to be significant at the 10% with a positive coefficient of 23.89. An explanation over the increased IM rate results could be attributed to the overall high level of IM in the US. A paper published in 2016 examining the IM rates in America believes that a potential reason why the US is nearly the highest ranked OCED country in IM rates is due to growing socioeconomic inequality in the nation (Lorenz, et al., 2016). The widening poverty gaps across the country resulting in rising IM rates in States less wealthy by a larger proportion than possible decreases in wealthier States. Overall, potentially resulting in the harmful rise in figures.

5.8 Key points

The main points uncovered in the results suggest that the RGGI has been an effective policy in reducing the consumption of the main energy sources that produce harmful carbon emissions. Reductions in coal, petroleum, and natural gas since the beginning of the system in 2008 bode well for the US's contribution in the current global struggle to reduce the severity of the damage inflicted by climate change. The insignificance of the effects on crude infant mortality are surprising suggesting that the model could be suffering from the omission of key variables considering the wide range of factors that can affect the health of new-born children. The positive effects on male crude mortality rates were another unexpected result seeing as all past literature would suggest a wide array of health benefits associated with the reduction of carbon emissions. However as previously discussed this could be attributed to the higher elderly population in affluent Western countries. If the policy were to be replicated in a less prosperous nation it could be argued that the results would show the expected significant decrease in crude mortality rates.

6 Conclusion

The key research of the paper was to firstly evaluate the effectiveness of the RGGI program on reducing the consumption of key energy sources that make up the majority of the total electric power sector. Analysis of the data revealed that due to the impact of the policy set in place in 2008, there has been a reduction in coal, petroleum, natural gas, and hydroelectric consumption in RGGI states by 83.30%, 67.70%, 44.35% and 7.78% respectively. There was also an overall decrease in the total energy consumption in the market by -17.22%. Wood derived fuel, wind and nuclear energy all tested insignificant. Secondly, after examining the effect on health that the policy had, total crude mortality rates proved to be insignificant at all levels but after separating the total rate by gender, female rates were insignificant whilst male crude mortality saw an increase by 9.05 per 100,000 people per unit change in the policy. Infant mortality was found to be insignificant at all levels for total, male and female crude rates.

The research question in my investigation was whether the RGGI has statistically decreased the consumption of individual energy sources and seen through the significant reductions of the largest carbon emissions producers it can be stated that the policy was successful and effective. Clearly there were a select few sources that resulted in insignificant change in nuclear, wood derived fuel and wind, however owing to the fact that they produce substantially less CO_2 when consumed, one could conclude the program to be reasonably effective. The fact that total energy consumption only saw a 17.22% decline whilst the reduction in coal, petroleum and natural gas were all larger, speaks once again to the success of the policy in its ability to maintain the electric power sector production in the country whilst reducing the main pollutant sources.

The main contribution of my research is to provide recent statistical analysis of the effects of the RGGI over a two-decade period, 2000-2020, on the breakdown of individual energy sources. The significance of investigating the effects in this way as opposed to the total electric power sector allows policy makers to make informed decisions on the future of the program now that a considerable amount of time has passed since it was first implemented. The analysis evidently reveals which energy sources have been affected by the policy and which have not significantly changed, leading to the possible need to target those sources with new additional policy with the intent to bring the overall carbon emission rate down.

There may be some possible limitations of this study, the lack of data for wood derived fuel, hydroelectric consumption and the non-carbon intensive energy sources causes certain constraints to the analysis of those regressions in a number of ways, including causing bias in the estimate parameters. As the investigation was run over a considerable period even with missing data points there was enough evidence to be able to come to accurate conclusions. Another potential limitation is that due to the focussed nature of the investigation into the effect of specific energy sources on the RGGI, the academic literature surrounding the topic was limited however the economic framework of DID has been effectively implemented before and so was successfully manipulated to fit the intended regression analysis for this research. With respect to the accuracy of the data collected they were all obtained from well-respected and unbiased organisations and so limitations of the data were minimal. As with most current empirical research, the longer time that has passed after a policy introduction, the more data there will be to analyse, meaning that time is a limiting factor. Fortunately, the 12-year period in this study is a substantial enough time frame to be able to draw definite conclusions.

In terms of future policy, the effectiveness of the RGGI on the main pollutant energy sources is high and so maintaining the core plan objectives along with the current execution strategy is valuable, however may not be entirely optimal. The reductions seen in coal, natural gas and petroleum are significant, although there is now evidence to suggest alternative routes for the future of the initiative, ultimately to still meet the same goal of overall decreased carbon emissions. The recommendation for future policy based on the results accumulated in this research would be firstly to guide policy in the direction of increasing the proportion of renewable energy consumption in the total electric power market. The data collection process for renewable and non-carbon-intensive energy sources must be held to the same high standards as the main energy contributors in order to accurately observe the progress in the sector. Other than wind and nuclear energy sources which were insignificant, there was a limitation in the data availability of the renewable energy sector. By intensifying the research and development process for renewable energy, it provides a way for firms to decrease their fossil fuel consumption without the fear of decreasing output and therefore profits. The switch from carbon-intensive fuels to renewable fuels is only constrained by the need for firms to keep output at a high and profitable level. By developing the renewable sector until it becomes as efficient in output as it is using coal for example, it will in the long term eliminate all need for the use of coal in the energy market and succeed in the global aim to minimise the damage of Climate Change.

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