

# Synthetic Control Method for Estimating the Effect of the Climate Change Act of 2008 in Britain

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## Abstract

*Climate change has brought along a series of complex challenges. Among these challenges, reducing emissions has proven to be a complicated endeavour and has subsequently been increasingly important in policy agendas worldwide. This paper is an empirical study on the causal relationship between innovative climate change policies and air pollution. Using the synthetic control method, I focus my analysis on the 2008 Climate Change Policy in the UK and CO<sub>2</sub> emissions and emissions from transport contributing to air pollution, including a robust literature review on the relevant aspects of climate change and air quality. This paper seeks to quasi-experimentally establish the role of climate policies in fighting some of the negative effects of climate change, namely, the effects of air quality and atmospheric carbon. The model output shows evidence regarding the policy's positive effect in reducing emissions from transport but fails to do so for CO<sub>2</sub> emissions. These findings harbour some hope for the effectiveness of climate policy regarding short-lived chemicals in the atmosphere and prove that more work is needed to curb high CO<sub>2</sub> concentrations and highlights the need for additional research on this topic.*

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## Introduction

This project addresses a small part of what is largely considered the biggest crisis facing humanity within the next century. Climate change poses a massive threat to many people's livelihood, suggests substantial economic losses, and threatens large scale environmental degradation. The importance of tackling climate change has become increasingly apparent in the minds of scientists, the general population, and policymakers worldwide. In addition to climate change, environmental issues such as air quality are also of paramount importance given their immediate effect on human health, high economic costs, restriction of human livelihood, and environmental damage. The UK has set itself on the international stage as one of the climate leaders, tackling head-on emission reductions across the board, the energy transition, and research and development into climate science. The 2008 Climate Change Act (CCA), an innovative policy, sets up a broad framework to tackle climate and air pollution issues with a novel legally binding mechanism, built with ambitious long-term goals, short term goal setting as a safeguard, and the creation of an independent body for measuring and monitoring, and consulting the government, as well as keeping it accountable to itself. Through the synthetic control model (SCM), this paper looks at the effects the policy had over total CO<sub>2</sub> emissions and emissions from transport, including NO<sub>x</sub>, VOCs, and PM<sub>10</sub>.

Considering the rate of change and the timescales needed to get to a viable solution for climate change, policy evaluation plays a huge role in improving and crafting better policies. The importance of policy evaluation cannot be understated. Much qualitative research has been done evaluating policies broadly. Still, the question of causal inference is a much more complex one to

ask, which is why this paper provides a valuable contribution to the literature on climate policy. This paper seeks to contribute to the field by offering a novel quantitative perspective into the matter of causal inference for building effective climate policy. Assessing this policy's performance is key to understanding the successes or failures that the policy might have. Linking CO<sub>2</sub> emissions and emissions from transport to single policy implementation is a challenging task. This paper seeks to add to the knowledge on climate policy and identify the effect this innovative policy has on specific emission types.

The literature review takes a deep dive into the main topics of importance by addressing climate change concerns, air pollution, and climate policy. I aim to deeply dive into ways in which we can effectively measure the impact of climate policies and get a sense of what the consensus in the literature is about the impacts of the CCA on emissions. The data section discusses the sources, quality, and description of the dataset and respective variables to understand the estimation method better. The methods section discusses the SCM choice and deep dives into its strengths, limitations, and threats specific to the analysis presented. The results section displays the outputs from the model and a thorough walkthrough and interpretation of results. Additionally, the results section presents a series of robustness tests to check the estimates' reliability. The discussion section goes further into reading what the results actually tell us and how these should be interpreted broadly, further assessing reliability and significance moving forward. The policy implications section seeks to dissect aspects of the literature and the empirical study, to draw meaningful implications for policy moving forward. This section analyses the structure and effectiveness of the policy and points out weaknesses and

learnings from this case. The conclusions section seeks to close up the paper with a reflective tone, highlighting significant results found, as well as proposing future research.

## Snapshot of Results

This paper makes use of the synthetic control model (SCM) to establish the relation between our treatment, the Climate Change Act of 2008 (CCA), and outcome variables, emissions from transport and total CO<sub>2</sub> emissions. This analysis finds a significant impact on emissions from transport but fails to do so for CO<sub>2</sub>. Additionally, this analysis looks into the workings of the policy through analysis of the literature alongside the results provided by the empirical study. The findings suggest that the CCA has many admirable aspects to be preserved and replicated globally and important deficiencies in achieving long-term targets. The following figures show the output of the SCM, showing the treatment effect graphically for both variables.

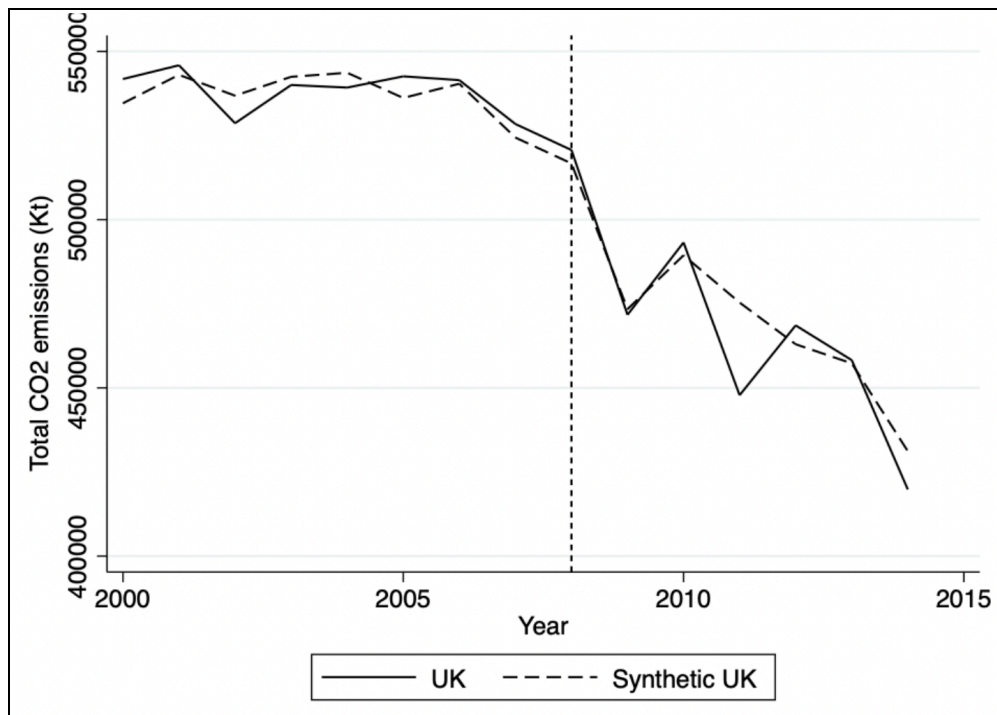


Figure 1. Synthetic control output for Total CO<sub>2</sub> emissions. This graph shows the results from the model, showing the comparison between the real data, and the synthetic control, where the policy was never

implemented. This graph shows a good pre-treatment fit, but no conclusive evidence to show a difference after treatment.

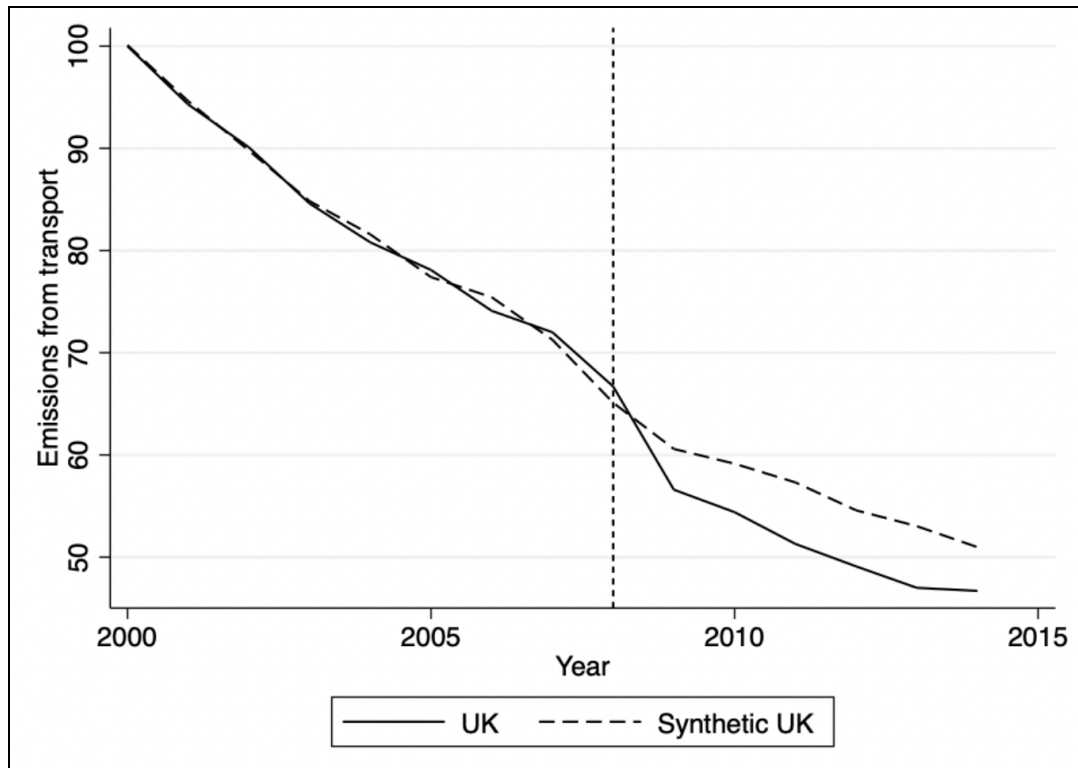


Figure 1. Synthetic control output for emissions from transport. This figure displays the results from the model, showing a good pre-treatment fit, and a clear separation between both lines after the treatment.

Further analysis and interpretation follow in the results, discussion, and policy implication sections.

## Literature Review

### Climate, action, and implications

Currently, measurements indicate 412 ppm of CO<sub>2</sub> in the atmosphere, amounting to the highest readings in around 650,000 years (NASA). Giving way to modern research, papers such as Hansen et al. (1981), highlight the importance of crafting policy based on scientific

knowledge. This famous paper shows and forecasts the effects of anthropogenic carbon dioxide warming in the centuries to come. Changing climate is a naturally occurring phenomenon seen across the history of Earth. Hansen (1981) spoke about the creation of drought-prone regions in North America and central Asia as part of a shifting of climatic zones and warned about the West Antarctic ice sheet's erosion with a consequent worldwide rise in sea level to be seen in the 21st century. As confirmed by important agencies such as NASA, we have seen increasing temperatures, increased sea levels, and an increasingly volatile climate bringing about droughts in North American and Asia, reinforcing the notion of connecting science with policymaking.

Scientists have proposed the Anthropocene, a new geological era ending the Holocene, a 12,000 year-long epoch characterized by the relative stability of climate in which human civilization developed after the ice age (Carrington, 2016). In geological timescales, this represents a massive change, which has been brought about mainly by human activity of the surface of Earth, including mass extinction of species, sea-level rise, carbon dioxide emissions, and the transformation of Earth's surface from development and deforestation, giving way to issues such as increased erosion, soil acidification, and prevalent droughts (Carrington, 2016). This idea of a new geological epoch still generates controversy among politicians and scientists who have not arrived at a definite consensus yet, demanding more research into the changes by employing improved technologies to measure and monitor the Earth system and its implications. However, evidence of anthropogenic climate change is unequivocal, is increasingly dominating the domestic and foreign public agenda (IPCC, 2014).

## Air pollution

Clean air is essential for human health, wellbeing, the economy, and the environment (DEFRA, 2020). Many problems exist, mainly in cities, regarding air pollution globally. First, it is crucial to identify some of the main compounds that negatively affect air quality. The main contributors to the air pollution issue are particulate matter (PM), nitrogen oxides (NO<sub>x</sub>), volatile organic compounds (VOCs), sulphur dioxide (SO<sub>2</sub>), and ozone (O<sub>3</sub>).

Particulate matter is typically quantified in the literature as PM<sub>2.5</sub> or PM<sub>10</sub>. Particulates are everything in the atmosphere that is not a gas, comprising many different chemical compounds, many of which can be toxic (DEFRA, 2020). These particulates are measured by size and divided into different groups, with 2.5 and 10 being respective numbers for diameter size in micrometres. PM can originate from natural or anthropogenic sources, for example, sea breeze or pollen, or wood-burning, or tyre and brake wear from vehicles. As the particulates are extremely small, they can penetrate the bloodstream and have different adverse effects on health and the respiratory system (EPA, 2020).

Nitrogen oxides are mainly sourced from the combustion of fossil fuels, or more importantly, from incomplete combustion, created very often from vehicles (Jacob, 1999). These pollutants shift between nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>) in the atmosphere very rapidly and are also reversible, which is why we use the form NO<sub>x</sub> for analytical purposes. This pollutant is not only bad for health but also participates as an input for the generation of ozone, which will be later discussed (DEFRA, 2020)(EPA, 2020).

Volatile organic compounds (VOCs) are an extensive group of organic compounds with a wide array of chemical makeup. These can be sourced from combustion, vapour from petrol, and many other urban uses. VOCs have adverse effects on human health, as many formations have been identified as toxic or carcinogens (DEFRA, 2020). VOCs have a larger effect indoors, but they also react in the atmosphere and photolyze to create ozone and other pollutants.

Sulphur dioxide is a corrosive acid gas produced from coal and the burning of crude oil. This compound is associated with asthma and chronic bronchitis as it primarily attacks the airways (DEFRA, 2020). One of the biggest concerns from this specific pollutant is the fact that it is the primary ingredient for acid rain, and as such, can travel large distances in the atmosphere and have an impact on human life, ecosystems, and habitat biodiversity (Jacob, 1999)(DEFRA, 2020).

Ozone poses risks to health by triggering inflammation and asthma and causes oxidative damage in vegetation such as crops (DEFRA, 2020). Ozone is toxic to humans and vegetation because it oxidizes biological tissue (Jacob, 1999). Additional concerns over ozone include the hardships and challenges faced for creating effective policy. The way in which ozone is produced will determine the best course of action, as not all methods are equally effective across chemical regimes. As previously mentioned NO<sub>x</sub> plays a fundamental role in the cyclical formation of ozone. The chemical regimes in different locations are not always consistent, requiring different approaches to deal with the problem.

#### *Air pollution effects on health*

Pollutants have been at the centre of how the atmosphere's composition has drastically changed. Air pollution has both acute and chronic effects on human health, affecting different

parts of the human body, including systems and organs (Kampa & Castanas, 2008)(Cohen et al., 2006). Health outcomes, healthcare costs, and even life expectancy have been affected by exposure to low air quality, mainly in cities. Kampa & Castanas (2008) and Brunekreef & Holgate (2002) have found heavy evidence supporting hospital admissions and higher mortality rates after exposure to air pollutants.

Exposure to air pollution, as noted, can be harmful to human health in a plethora of ways. Still, different levels of exposure exist, mainly creating a divide between urban and rural centres. Air pollution is the leading environmental cause for early death, accounting for about 5% of deaths worldwide (World Health Organization, 2017). In the UK alone, pollution has led to approximately 30,000 early deaths, stressing the massive impact on human health globally and locally (Public Health England, 2018). The implementation of the Clean Air Strategy 2019 seeks to focus more specifically on the particular emissions that give rise to chemicals with detrimental effects on health.

#### Air pollution effects on ecosystem

Compared to the human impact, there are many hardships when quantifying and analyzing the damage of air pollution in multiple ecosystems. As discussed above, some pollutants are prone to be toxic for animal and plant habitats, with the additional concern that they may be corrosive, leading to more ecosystem degradation down the line. However, the ecosystem's impact is also something to be mindful of, as there is real value being provided to humans from ecosystem services. Around 58% of terrestrial habitats and ecosystems have been impacted to varying levels of degree by human air pollution (DEFRA, 2010). This number has lowered since more strict controls have been set over sulfur generally. Still, the threat of

acidification of waterways through air pollution deposition and acid rain remains high. It threatens valuable ecosystem services such as pollination, soil capacity for agriculture, and aesthetic or cultural value.

#### Air pollution effects on the economy

The economy is also a target of the air pollution issue. And although there is a direct cost of air pollution through hospitalization, more factors are to be considered as air pollution hinders economic performance. Air pollution affects the economy by the cost in human life, reducing people's ability to work, affects the production of critical goods such as food, damages historical and cultural monuments, stops vital ecosystem services that need a cost for remediation (UNECE, 2016). More punctually, the Public Health England report of 2008 has shown the estimated combined cost of PM<sub>2.5</sub> and NO<sub>x</sub> on the National Health Service (NHS) in 2017 to be £42.88 million (Public Health England, 2018). Further issues with air pollution include social instability and a loss of investments for the region, resulting in fewer companies and investments to be made due to poor life quality in polluted regions (Ma, 2017). On a conclusive note, issues with the quality and availability of data have often hindered our understanding and appropriate responses. New technologies are proving to be essential in keeping up with this demand for data, and have also improved the way we understand air pollution (Environmental Defense Fund, 2019).

#### Climate policy

Climate policy aims at tackling some of the most important issues concerning environmental security but has a primary focus on climate change. Climate policy exists on

many levels and has evolved dramatically over the past five decades. Climate policy is crafted and created on a local, national, regional, international, and global scale, which adds a certain degree of complexity as policies interact across levels.

#### Evolution of climate policy

Climate policy has evolved consistently since the 1970s, when the first environmental protection acts were implemented. Recently, climate policy has moved as fast as it ever has due to new scientific information, ultimately guiding the policymaking process for tackling issues such as extreme emission of greenhouse gasses, ozone layer depletion, air pollution, and resource management. The evolution of climate regimes is a cumbersome process, having many issues resulting in a great political effort to resolve (Schiele, 2014). Climate policy has also evolved from being locally driven to internationally driven, as the scope of the problem has been broadly recognized to be global. The process for climate policy evolution requires changes and implementation of new norms and international law to maintain procedural order and efficiency, given the time scale of the problem (Schiele, 2014).

#### International level policy

Climate change needs international cooperation, as the risk is global. Tasks required to mitigate and adapt to the problem are global, leading to the need for global collaboration, culminating in the Paris Agreement. The Paris agreement is a worldwide scale plan to limit global warming in the long-term. For this, countries have agreed to reduce emissions, use technology to be more efficient, and ultimately attempt to transition into clean energy sources. This agreement fundamentally changed the paradigm of climate diplomacy, as it allows countries

to determine their contributions, rely on norms and expectations over the law, has a hybrid legally binding model, and balances top-down and bottom-up approaches to maximise buy-in and outcomes (Stern, 2018). Moving faster than any large-scale agreement before, the Paris Agreements seems to be a force to be reckoned with. However, challenges are still on the horizon. Countries have been able to feel the support for development, unlike previous agreements such as the Kyoto Protocol. The big question regarding the success or failure of the Paris agreement is the extent to which nations will comply with the contributions submitted. Having a "rulebook" is essential in this case, like compliance and strong leadership have proven to be issues and the key to success (Stern, 2018).

The Paris agreement has been a milestone in human history, as it is viewed as one of the most successful diplomatic feats in history; however, performance upon those promises is a different topic. Roelfsema et al. (2020) find through computational modelling and prediction techniques that most countries are not keeping up with their pledged national contributions. In order to be on track to reaching the long-term goals, an increase in pace would be necessary.

Many challenges exist when evaluating climate policy. Uitto et al. (2017) have identified some of the main problems to be: climate projects tend to be large scale, interconnected, and spread across branches, internal logic being inconsistent, and strategic assessments tend to lose relevance rapidly, as new decisions are made, and political and institutional contexts change.

Attempting to tackle some of the issues with evaluating policy, Isaksen (2018) has looked at the impact of the Long-Range Transboundary Air Pollution (LRTAP) protocols on specific pollutants using the synthetic control model. This paper finds that the LRTAP reduced emissions significantly further than the constructed counterfactual. This modelling method deals

with non-parallel trends by creating a synthetic counterfactual, as opposed to comparing unparallel units. Bueno & Valente (2018) also use the synthetic control model to estimate the effect of unit pricing systems in waste generation. As an example of evaluating climate policy, this paper finds significant results that the policy effectively reduced waste and increased recycling by a smaller percentage. Taking a different approach, The Comparing Climate Change Policy Networks (COMPON) seeks to set causal relations for climate policy through network analysis. Ylä-Anttila et al. (2018), on the other hand, recommend the usage of Qualitative Comparative Analysis as one solution for combining different levels of analysis and being able to make use of quantitative, qualitative, and network data.

Moving closer to the area studied in this paper, Almer & Winkler (2017) assess the impacts on emissions from the Kyoto Protocol on Annex B countries. They use synthetic control but find little evidence to support significant emission reduction in said countries. Part of their approach relied on analysing at a country group level, which poses some limitations on the model performance due to the fact that the Annex system can create issues with building viable controls. Similar approaches have been used successfully for evaluating climate policy by Sills et al. (2015) and Steinkraus (2019), showing the evaluative power and fit for climate of the model and the trustworthiness of the results.

Looking specifically at evaluations of the CCA, many approaches have been based on political analysis and qualitative evaluations of success based on outcome values. Fankhauser, Averchenkova, and Finnegan (2018) conduct a robust investigation of the CCA, analysing its performance and individual parts over ten years, concluding that some of the most considerable successes of the CCA are the following:

- Setting up a comprehensive framework law to coordinate and advance climate action (Fankhauser, Averchenkova & Finnegan, 2018)
- Sets up 5-year targets that offer clear direction, space for monitoring, and a chance to revisit or alter the plan flexibly (Fankhauser, Averchenkova & Finnegan, 2018)
- The formation of a strong independent body, the Committee on Climate Change (CCC), to ensure consistent policy delivery and evidence-based decision-making (Fankhauser, Averchenkova & Finnegan, 2018)

Pielke (2009) makes a critical evaluation using top-down and bottom-up evaluations of the long-term goals but shows a much different outlook, putting forward the idea that the goals might be too ambitious and expects the policy to fail. These two approaches have identified strengths and weaknesses and have evaluated the policy's performance so far; however, there is a missing piece in the literature, referring to queue quantitative analysis for the policy's treatment effect on specific important indicators. Isaksen (2018) offers estimations for the treatment effect of air pollution policy on specific pollutants, and this paper seeks to fill in the gap in the literature with a similar approach by quantifying and demonstrating the treatment effect of the CCA on both CO<sub>2</sub> emissions and emissions from transport contributing to air pollution. The following section takes a deep dive into the policy being evaluated to understand better the evaluation and the estimate presented in the results section.

### Climate Change Act 2008

The United Kingdom boasts one of the most ambitious climate policies globally: the 2008 Climate Change Act (UK Government, 2008). This policy is innovative as it is the world's

first legally binding unconditional national legislation to reduce greenhouse gas emissions (Lorenzoni & Benson, 2014). The UK has long been established as a leader in international climate change agreements as one of the most innovative countries to tackle the problem domestically by introducing policy instruments such as tax levies, fuel duties and emissions trading for this purpose (Lorenzoni & Benson, 2014).

The CCA of 2008 is a large-scale commitment to emissions reductions. It is situated on a national level, affecting the entire United Kingdom and only affecting the nation. It is important to situate this climate change act as national policy acting, while international and regional policies are also at play. For example, the European Union sets emissions targets and acts in all of the countries composing it. Additionally, the introduction of the Paris Agreement adds a different level over national policies, which mostly coordinate with each other. However, the interaction is still worth mentioning, although it came almost eight years after the domestic implementation of the CCA. The compliance with broader multilateral agreements or accords adds complexity to the system. The CCA is a domestic policy, and the accountability for this is only to the British government, which has also been part of larger agreements. Usually, the interaction works well by pushing the boundaries further, and in this case, the CCA made more ambitious commitments than those already set by the EU and large protocols such as the Kyoto protocol (UK Government, 2008). The arrival of the Paris Agreement is a game-changer, in the sense that the CCA will need to adapt to continue being effective in reaching globally set long term goals (Fankhauser, Averchenkova & Finnegan, 2018).

Getting more specific, the CCA sets up a lengthy, legally binding set of targets to be

fulfilled by 2050 with multi-year targets to provide direction and flexibility.

Additionally, one of the most important pieces of the CCA is that it sets up a strong independent body (Committee on Climate Change; CCC) to advise and oversee implementation of the policy (Grantham Research Institute on Climate Change and the Environment, 2010). As mentioned in the climate policy section, this is one of the key factors for success and has been an item for replication globally. This independent body has proven crucial for scientific consultation, supervision, and making sure the government adheres to its promises. The importance of this supervisory community can not be understated. Being an unbiased, mostly scientific organization, the CC provides direction and annual reports to make sure the goals are met accordingly (Committee on Climate Change, 2019). Another crucial implementation is the 5-year budgets that provide direction, specific goals, an assignment of responsibilities, and the chance to be flexible in reaching long term goals. This is to make the problem more tractable by breaking it down into smaller "checkpoints" that serve as stepping stones to track and monitor large-scale progress. In addition to these checkpoints as emission caps and specific goals, the government is mandated to send in a full climate change risk report every five years (Grantham Research Institute on Climate Change and the Environment, 2010). Additional aspects of the policy include easier implementation of emission trading schemes and financial incentive schemes to deal with energy and waste management.

Most significant to this research, we want to look at the transportation aspect of the Low Carbon Transition Plan, which the CCA set up. The policy specifically targets the following objectives: improving fuel efficiency, supporting low carbon vehicles, research into future fuels, helping people choose low carbon transport options, limits on international aviation and shipping

emissions, and securing oil required during the transition period (HM Government, 2009). All of this has in mind two primary objectives: global warming and air quality. Looking individually, the goal of improving fuel efficiency has many sub-policies to reach this goal.

Improving fuel efficiency is one of the main goals for policy and technology innovators worldwide to reduce costs and lower the need for more fossil fuel extraction. In this plan, the government's policy will:

- Cut the permissible emissions from new cars by 40% by 2020 (90g/kg), with an additional checkpoint by 2015 (130g/Kg).
- Have all government vehicles for all purposes adhere to the restrictions by 2011.
- Push vehicle regulation agenda to the EU.
- Investing 30 million pounds to low carbon bus technology.
- Supporting low carbon vehicles has been placed as one of the priorities for the British government.
- Set more than 500 electric vehicles into circulation as part of a government program.
- Invest 30 million pounds into the installation of electric vehicle charging infrastructure.
- Source 10% of UK transport energy from sustainable renewable sources by 2020.
- Helping people choose low carbon transport options is a big aspect of being able to get at the consumer behavior, as a bottom up approach.
- Invest £29 million in a competition for the country's first Sustainable Travel City
- Investing £140 million between 2008-11 in Cycling England's programmes.
- Set limits on international aviation and shipping emissions can be an important cut of emissions for the UK.

- Commitment to working with the international community to agree on capping emissions from aviation, despite growing demand for air travel.

More on all of the individual policies can be found in The UK Low Carbon Transition Plan National Strategy (2009) for climate and energy under the transport sector.

## Data

This project heavily requires the usage of data. Given the choice of empirical study, panel data on European countries containing important and relevant covariates for the question was needed. As no dataset containing the variables of interest exists, I compiled data on different variables from 1990 to 2018, which is the most recent data for many indicators of interest. The individual indicators come primarily from the European Union Open Data Portal and the World Bank, regularly updated sources and contain official values reported on an aggregate level.

The data compilation and the creation of my dataset were done to find the most appropriate variables that act as predictors for the model. The methodology will be more deeply explained in the next section. However, it requires a "donor pool" to construct a synthetic counterfactual, which demands available data across all of the European countries through the same period. As the researcher ultimately chooses the experimental design through careful consideration and previous literature, the perfect dataset did not exist, motivating the compilation into a single dataset I carried out for this paper.

Similar to most prediction methods, predictor selection is an essential task towards the estimation effort. As a general practice for the SCM, the explanatory variables must be relevant to the dependent variable's makeup (Abadie, 2020).

As mentioned previously, the data used in this study is panel data, which takes several observations across different countries, but is not limited to one timestamp. The dataset describes the following variables: *country*, *year*, *pollutant emissions from transport*, *population*, *GDP per capita*, *purchasing power (adjusted GDP per capita)*, *price of gasoline (US dollars)*, *total CO<sub>2</sub> emissions*, *renewable energy share*, *population density*, and *area (sq km)* for all European countries starting in 1990 until 2018. For specificity and depth, I list all of the variables included in the dataset.

*Country*: The indicator with the country name. The dataset includes 31 European countries including the treated unit and the make up of the donor pool.

*Year*: Year in which the measurement was taken. The data includes years 1990 through to 2018.

*Pollutant emissions from transport*: Emissions from transport are the main contributor to air pollution (European Union Open Data Portal, 2019). Measured yearly, this variable represents an index (year 2000 = 100) for pollutants from transports measured across the country. More specifically, this indicator reports a composite value on nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOCs) and particulate matter (PM10), which are the main pollutants coming from transport usage. Emissions are officially reported under the UNECE Convention on Long-Range Transboundary Air Pollution.

*Population*: This indicator is commonly used in the literature as an explanatory variable. This indicator counts all of the people living in each European country yearly, not restricted to citizens. This variable allows us to get a size of the country and serves as an important predictor for emissions.

*GDP per capita:* A measure of economic growth accounting for the population measured yearly. GDP is one of the most used economic indicators and also serves as a good predictor for emissions of a nation.

*Purchasing power:* Represents a common currency that eliminates the differences in price levels between countries allowing meaningful volume comparisons of GDP and economic wealth.

*Price of gasoline:* Pump price for gasoline measured every two years starting in 1995, showing the price in US dollars for gasoline, which is an important predictor on emissions from transport specifically.

*Total CO<sub>2</sub> emissions:* Total amount of Carbon emissions per country measured yearly from 1990 to 2014. This indicator includes data from the Carbon Dioxide Information Analysis Center, measuring the results in Kilo-tonnes (Kt).

*Renewable energy share:* Renewable energy consumption as a percentage of total final energy consumption in the country. This indicator is an important predictor for emissions in a country.

*Population density:* Similar to the population variable, this variable is included in the dataset to account for the total population within the area of the country. This indicator allows us to see how many people live per square kilometer.

*Area:* This variable has the area per country, given in square kilometers. It is used to construct the population density values when missing, and to check the validity of the given values from the

To further look into the data and understand the context of UK emissions over time, Figures 1 and 2 show the time series for emissions from transport and from total  $CO_2$ , allowing us to look at the long term trends of emissions.

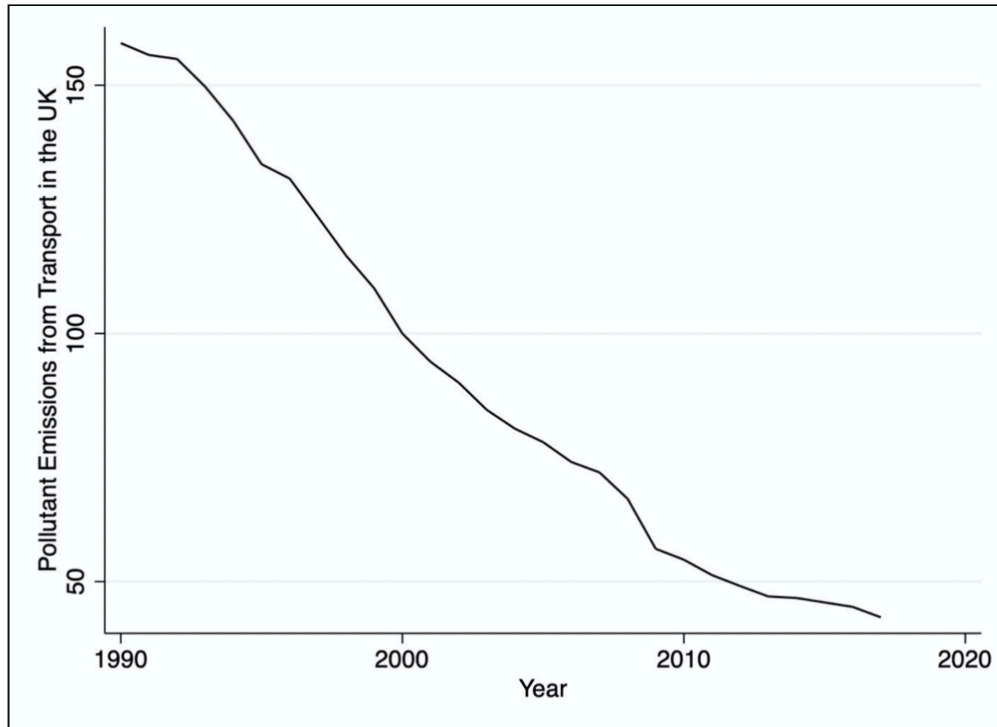


Figure 3. Pollutant emissions from transport in the UK over time. Values are given in index form, and show the trend over the past two decades. Data: (European Union Open Data Portal, 2019).

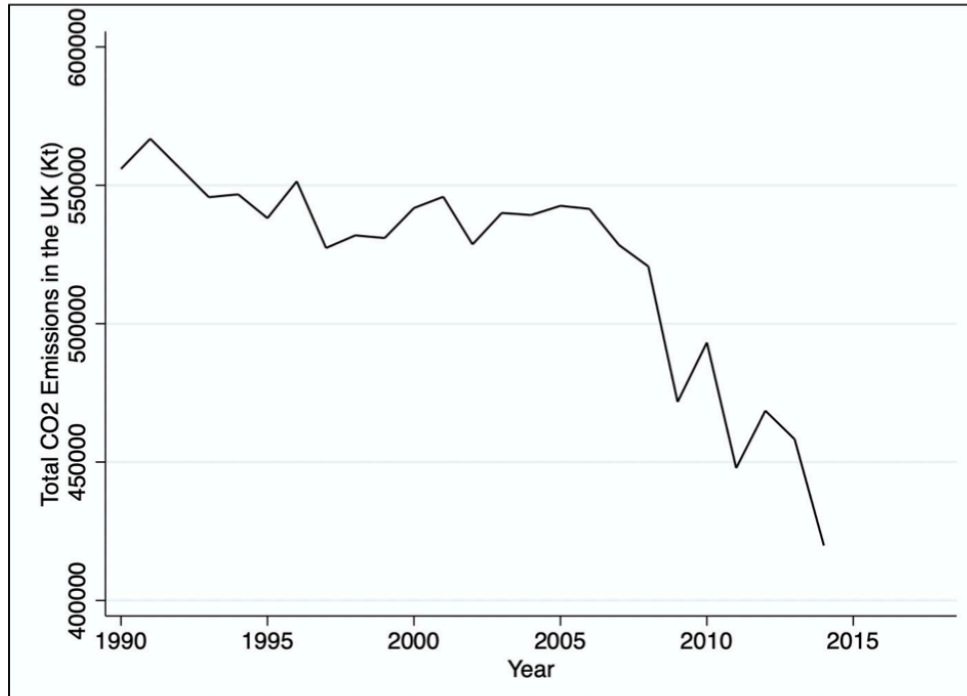


Figure 4. Total CO2 emissions from transport in the UK over time (measured in Kt). The values show the trend over the past two decades. Data: (World Bank, 2019).

It would also be useful to compare  $CO_2$  emissions in the UK to other european countries in our dataset at two different points in time, showing some more of the salient aspects in the data.

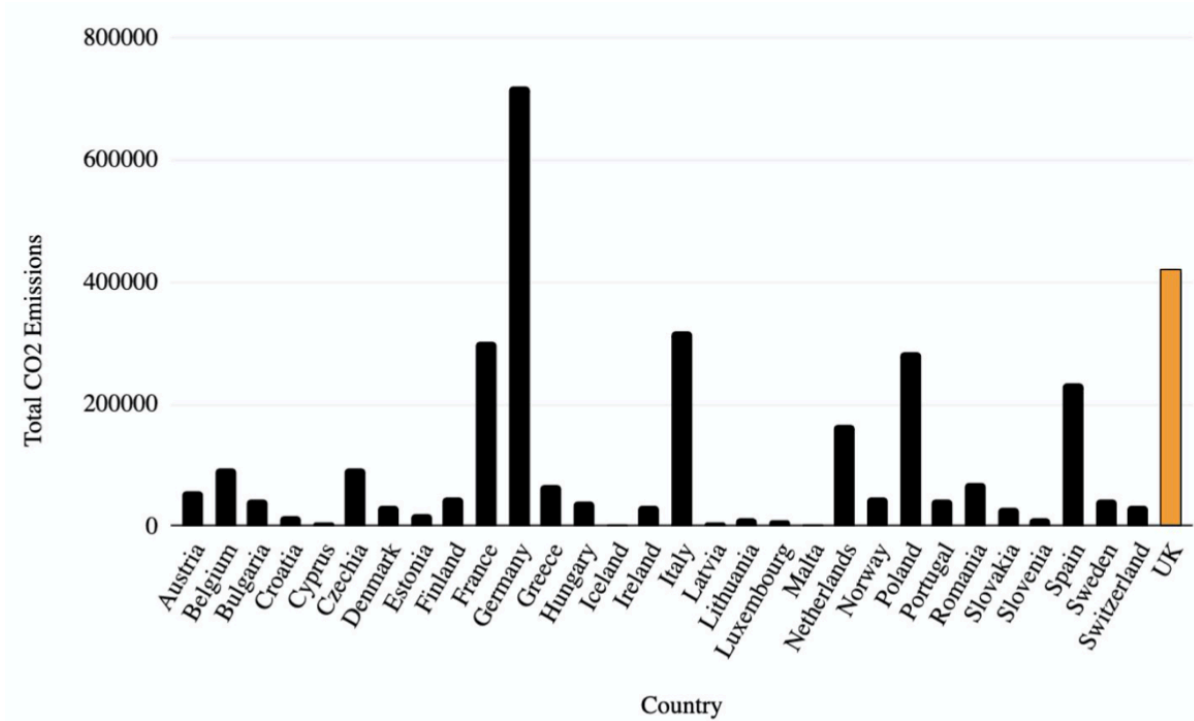


Figure 5. Total CO2 emissions in 2014 per country. This figure shows the emissions from each country, highlighting the role of the UK in Europe for 2014 specifically. Data: (World Bank, 2019).

## Methodology & Model Specification

I make use of the Synthetic Control Method (SCM) to create a comparative case study in which the creation of a synthetic UK serves as a counterfactual where the treatment never occurred (Cunningham, 2018). This counterfactual is based on a series of covariates obtained from a donor pool of data to compare the pretreatment and the post-treatment periods. Offering a counterfactual is offering a solution to the fundamental problem of causal inference, but as with all causal models, limitations exist. As in most econometric studies, we are concerned with unobservables that might affect, skew, or alter the results obtained from the model. Using this method has many advantages. For one, this method precludes extrapolation. It uses interpolation

instead because the causal effect is always calculated by comparing the vertical distance between the control and the treatment. Unlike regression, data processing does not need access to post-treatment data, which helps eliminate bias as there is no reason to "peek" at the data beforehand. Another advantage of the method is the fact that you can have different weights in making up the synthetic counterfactual; and additionally, the algorithm finds the optimal weights, removing subjective research bias (Abadie, Diamond, & Hainmueller, 2010). The SCM is also transparent as researchers can evaluate how well the synthetic control's outcome matches the affected region's outcome before the policy change, with the added benefit of known donor regions and exact weights provided (McClelland & Gault, 2017). The method was first introduced by Abadie and Gardeazabal (2003) and later extended in Abadie et al. (2010), where they estimate the effect of a large tobacco control program in California. Ultimately, the SCM is sparse, meaning that the model tends to give positive weights to a small number of units, while ordinary regression will give non-zero weights to most units (Abadie, 2020). This is an advantage because of its interpretability, making it easier to evaluate the estimated counterfactual. With causality being such a complex question to answer, the SCM allows us to take full advantage of the above-mentioned reasons to provide an answer. This approach provides a better way of understanding the impact estimation over classic regression or even other causal models such as regression discontinuity. By this, I mean to say that the SCM also deals with many of the unobservables by making use of an extensive data pool where global events affect all units.

Synthesizing the reasons for a synthetic control approach to be employed, the following lists some of the most salient reasons:

1. Precludes extrapolation.
2. Removes subjective researcher bias.
3. Shows transparency of counterfactual.
4. Sparsity.

This method relies on the assumptions listed below, and are derived from Abadie, Diamond, and Heinsmuller (2010), McClelland & Gault (2017), and Cunningham (2018):

1. Placebo assumption: Only the treated unit is affected by the policy in the periods employed for the model.
2. Time assumption: The policy has no effect before it is enacted, and there is no significant time lag for the policy to be initiated.
3. Counterfactual assumption: The counterfactual for the treated unit can be approximated by a combination of donor units or the donor pool.
4. Independence/Spillover Assumption: No other unit in the donor pool received a similar treatment in the studied period.

If the assumptions are correctly met, the synthetic control provides an estimation for the treatment effect of an intervention, providing a statistically sound counterfactual. As mentioned, the model also has some limitations. The following list provides some of the most salient limitations and considerations to be kept while developing and interpreting this type of empirical study.

1. Exogenous shocks can invalidate results (Johnes & Barrows, 2019). This is a risk that is taken in almost all methods for estimation, which can only be countered by attempting to avoid them or describe them into the model.

2. The model shows limited effectiveness in showing small effects (Johnes & Barrows, 2019).
3. Hard to establish to what extent the assumptions are met.

At this point, it is important to mention some of the potential threats to the assumptions that can affect the validity of the estimation. For the placebo assumption, I argue that as the policy is on a national level, enacted by the British Government, having jurisdiction only over the UK, the assumption is strong to make, and no substantial threats exist. For the time assumption, the policy has been globally renowned for being innovative and marks the first comprehensive legally binding policy on the national level, meaning that the policy did not have an effect before the treatment date. However, there is a small lag from declaring the policy to its implementation. Additionally, global trends for lowering emissions, based on technological advancements, have been building since knowledge on the negative effects of global warming became popular, which has an additional effect on emissions globally. For the counterfactual assumption, there is a strong case that a synthetic version of the UK can be approximated by units in the donor pool. Having data on most of the European region, we can make use of our variables described in the data section to approximate a counterfactual. For the spillover assumption, concerns over the strength of it exist due to the fact that climate policy is a rapidly changing and complex environment. Although the CCA marked a starting point incomparable climate policy, other nations in the EU might have developed similar policies years after this one, reducing the reliability of the results over the long term. For example, the introduction of the Paris Agreement significantly threatens this assumption as policies were implemented broadly in all countries within the EU. This agreement was signed in 2016, which is outside of the studied

period for both our variables, but these types of threats still exist from local level climate policies that followed the CCA in 2008.

The credibility and trustworthiness of the model and the synthetic control estimation depend on the capacity to track the outcome variable for the treated unit during an extended pre-intervention period (Abadie, 2020). In the next section, the synthetic control output will be shown, and we can use the fit of the model during the pre-treatment period as a good indicator of reliability.

## Results

In this paper, we are interested in looking at emissions of CO<sub>2</sub> and emissions from transport. This section will be split into the two sections and respective set of results.

### *Estimated impact of the 2008 CCA on CO<sub>2</sub> emissions:*

As discussed previously, a synthetic control for the United Kingdom is created to estimate the causal effects of the intervention on CO<sub>2</sub> emissions. The model is trained on data ranging from the year 1990 to 2008. The treatment begins in 2008, and the results show all the way into the year 2014, using our compiled dataset. Since no single unit is as good of a fit for the pre-treatment period, table 1 shows the predictor balance between the actual UK, synthetic UK, and values for Germany, the country with the most similar values for predictors.

Predictor Balance		
Predictor	Treated Unit Value	Synthetic Value
Population	58,800,000.	58,800,000.
PP	26375	26684.04

GDP per capita	24922.64	26461.11
Gas price	1.261667	1.230365
Share of Renewables	1.028368	4.362137

Table 1. Predictor Balance table.

This table shows the values for each predictor for the UK and the synthetic version. The goal is for the synthetic UK to be as similar as it possibly can, in order to make meaningful inferences from the model results. As it is made apparent, the table shows the fantastic performance between the UK and the counterfactual. The advantage this provides is that the inferences made from the model are likely to be accurate, in terms of having a good counterfactual.

In the construction of the synthetic counterfactual, units from the donor pool were selected, and as part of the transparency and sparsity of the method, the following table shows the exact weights within the donor pool.

Synthetic Control Weights

Country	Unit Weight
Belgium	0
Bulgaria	0
Czechia	0
Denmark	0
Germany	0.339
Estonia	0
Ireland	0
Greece	0
Spain	0
France	0

Croatia	0
Italy	0.5
Cyprus	0
Latvia	0
Lithuania	0
Luxembourg	0
Hungary	0
Malta	0
Netherlands	0.161
Austria	0
Poland	0
Portugal	0
Romania	0
Slovenia	0
Slovakia	0
Finland	0
Sweden	0
Iceland	0
Norway	0
Switzerland	0

Table 2. Table showing the unit weights for the synthetic control

In this case, the units that make up the synthetic UK are Italy, Germany, and the Netherlands, with all other units in the donor pool being given a value of 0. The following table displays the main output from the SCM, displaying graphically the treatment effect of the policy on CO2 emissions.

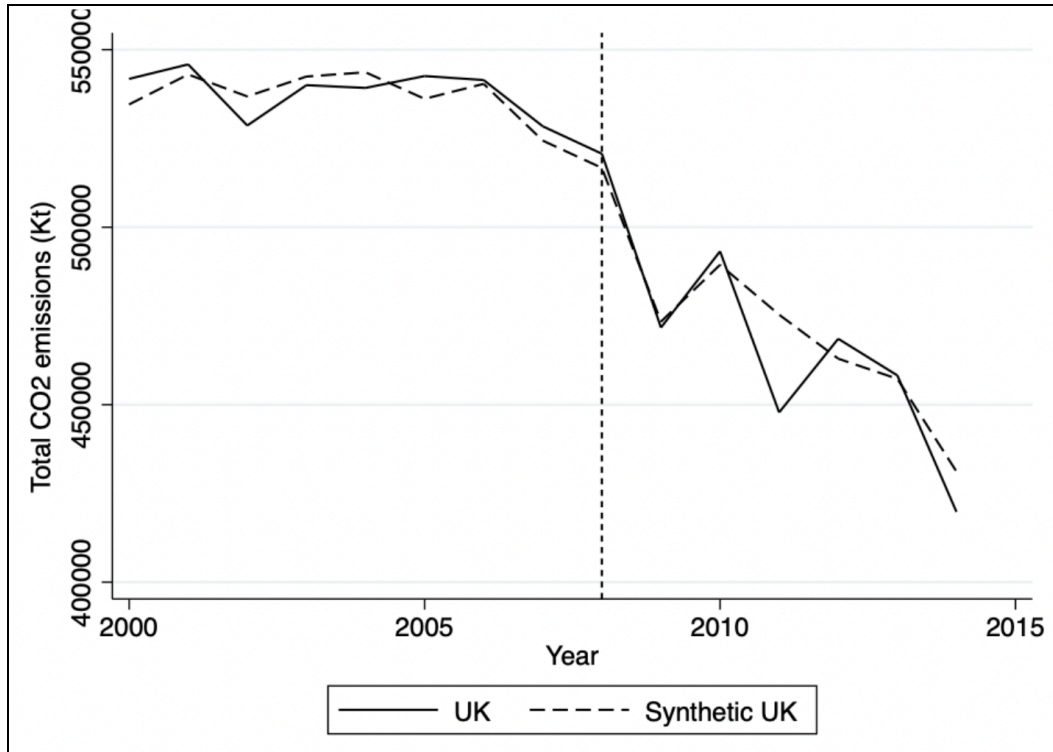


Figure 6. Synthetic control output for emissions from CO2. Note that the model is trained on data starting in 1990, but the figure only displays results starting in 2000 due to the ease for interpretation. The treatment period is also clearly marked with the vertical dotted line.

As we can see from the figure, the model performs well by mimicking the pre-treatment period pretty well. There seems to be no immediate effect, but rather a blip in the year 2011. The interpretation of these results confirm the performance of the model but fails to find a trend that implies a treatment effect. Given the limitation of the data, the model does not show the treatment effect of years past 2014. There seems to be no discernible treatment effect when it comes to CO2 emissions. This result suggests that the 2008 CCA had little to no effect on emissions from carbon, and might suggest instead exogenous interference during the year 2011.

The following figure displays the gap between the synthetic control and the treated unit, for better visualization on the treatment effect.

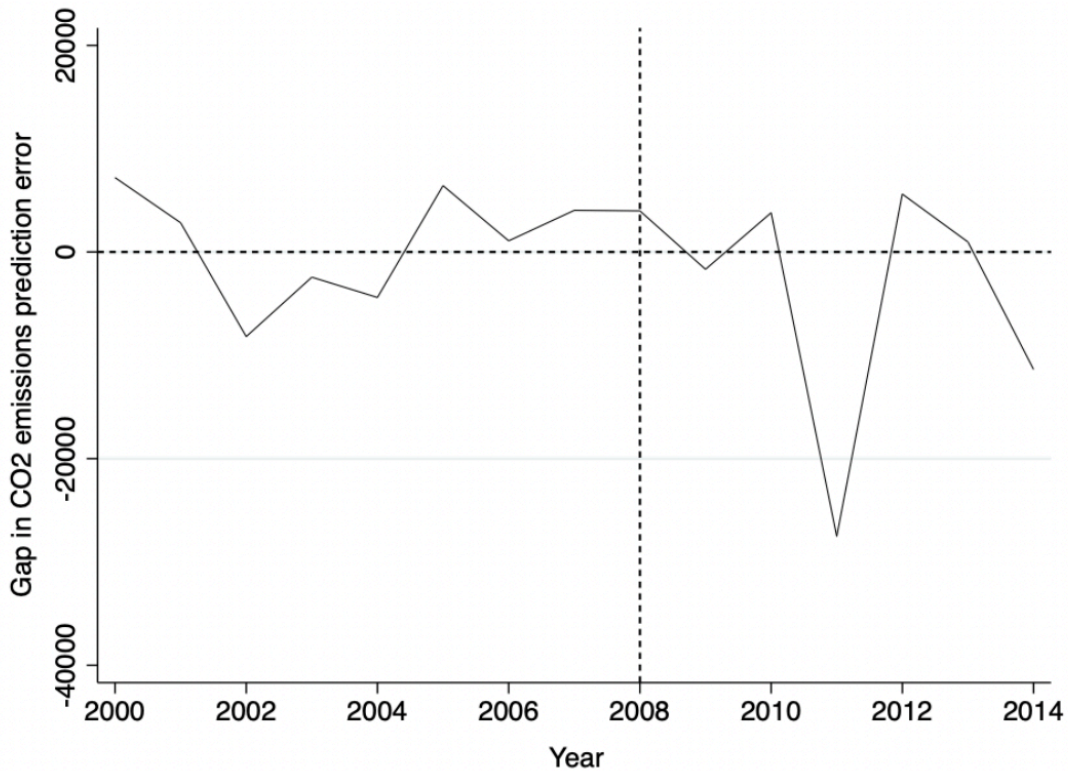


Figure 7. Gap in prediction error for the CO2 emissions to its synthetic control. This graph displays the difference between the synthetic UK and real UK, using the synthetic values as the x-axis to better show deviations.

As we can see, the gap seems to not show a particular trend stemming from the implementation of the policy. This is significant because it shows that although the UK has seen a steady decline in carbon emissions, this research suggests that it cannot be causally linked to this policy alone. This being said, the model performs well, as good predictor balance is reached, sparse weights are provided to the donor pool, and the pre-treatment period is somewhat aligned with the treated unit. The results are not clear in pointing out a treatment effect, and data availability restricts further measurements. Given the results, we will shift our focus on emissions from transport, which are more specifically targeted with immediate policies; whereas CO2 emissions are much broader, and are tougher to isolate and measure effectively (Pearce,

2018). At this point, more research is suggested at targeting the causal links between climate policy and CO<sub>2</sub> emissions at a local and global level.

*Estimated impact of the 2008 CCA on emissions from transport*

A synthetic control for the United Kingdom is created to estimate the causal effects of the intervention on emissions from transport. The model is trained on data ranging from the year 1990 to 2008. The treatment begins in 2008, and the results show all the way into the year 2014, using our compiled dataset. Since no single unit is as good of a fit for the pre-treatment period, table 1 shows the predictor balance between the actual UK, synthetic UK, and values for Germany.

Predictor Balance	Treated Unit Value	Synthetic Value
Population	$5.88 \times 10^7$	$5.27 \times 10^7$
GDP per capita	24922.64	24945.29
Share of renewables	1.261667	1.18985
Emissions from transport (1990)	158.5	129.3571
Emissions from transport (2001)	94.3	94.6263
Emissions from transport (2007)	72	71.2676

Table 3. Predictor Balance table.

This predictor balance table allows us to be able to get at one of the biggest strengths of this method. The creation of a synthetic counterfactual that fits closely with the pre-treatment

treated unit. The table shows the fit of the values, and with the notable exception of the share of renewables, the synthetic UK provides values that closely resemble the true data. As we can see from the table, the synthetic UK performs is much more closely related to the UK's real data than any other option.

In the construction of the synthetic counterfactual, units from the donor pool were selected, and as part of the transparency and sparsity of the method, the following table shows the exact weights within the donor pool.

Synthetic Control Weights

Country	Unit Weight
Belgium	0
Bulgaria	0
Czechia	0
Denmark	0
Germany	0.55
Estonia	0
Ireland	0
Greece	0
Spain	0
France	0.061
Croatia	0
Italy	0.5
Cyprus	0
Latvia	0
Lithuania	0
Luxembourg	0
Hungary	0

Malta	0
Netherlands	0.001
Austria	0
Poland	0.06
Portugal	0
Romania	0
Slovenia	0
Slovakia	0
Finland	0.329
Sweden	0
Iceland	0
Norway	0
Switzerland	0

Table 4. Table showing the unit weights for the synthetic control.

The next figure shows the main output of the model, displaying graphically the treatment effect of the policy on emissions from transport. As discussed and as seen in the table of weights, the synthetic UK is based on a combination of Germany, France, Netherlands, Poland, and Finland.

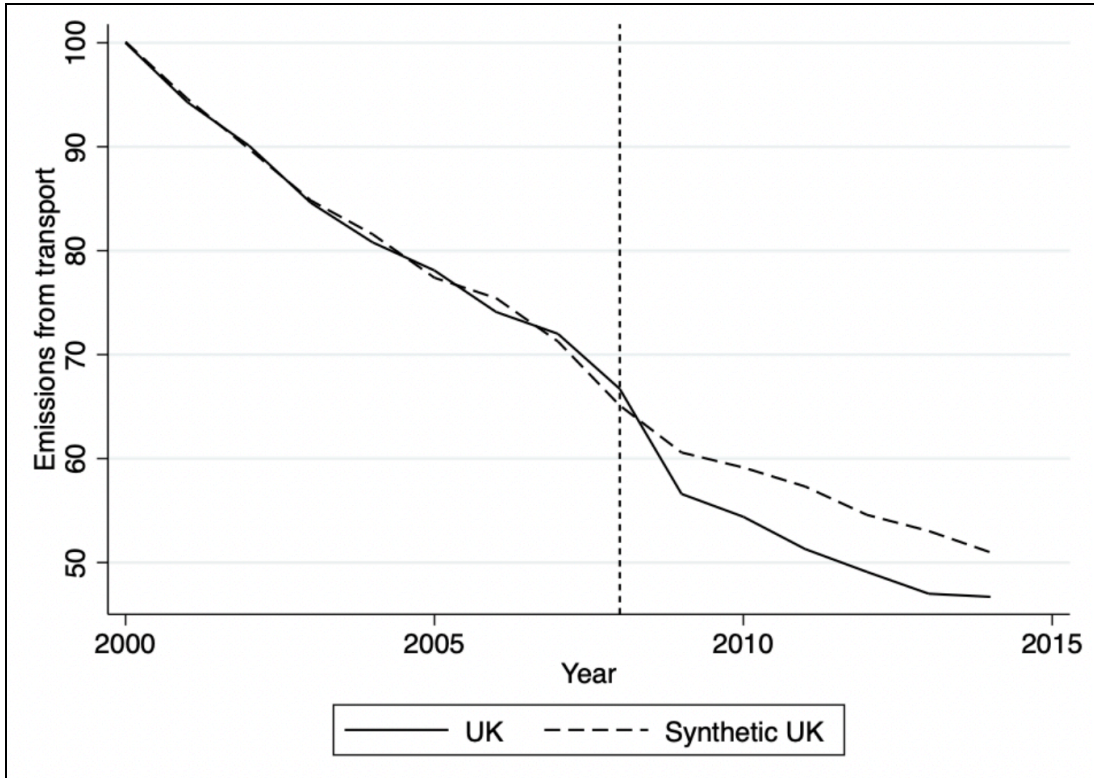


Figure 8. Synthetic control output for emissions from transport. This figure shows data starting from the year 2000, and displays the difference between the UK and the Synthetic UK. The treatment period is also clearly marked with the vertical dotted line.

As shown in the figure, almost immediately after the passage of the Climate change act, there is an important deviation from the synthetic control. The short period it takes before deviating can be accredited to a lagged effect due to the complexity and time-intensive nature of the policy's implementation. As outlined, the policy targets many different aspects of air quality and acts in different ways by setting restrictions and incentivizing

The discrepancy between the lines suggests a negative effect on emissions that has been sustained over time. More specifically, there seems to be a sustained gap at around 4 index points lower than the synthetic UK. The policy seems to have had a significant effect on the reduction of emissions from transport and to further test this observation, we want to be sure to have adequate tools for evaluation. The following figure shows the gap in prediction error, which

represents the deviation between the UK, and its synthetic counterfactual, allowing for a useful visualization of the treatment effect. This graph also illuminates the effect size and shows how the model performed well, by tracking the pre-treatment values very closely.

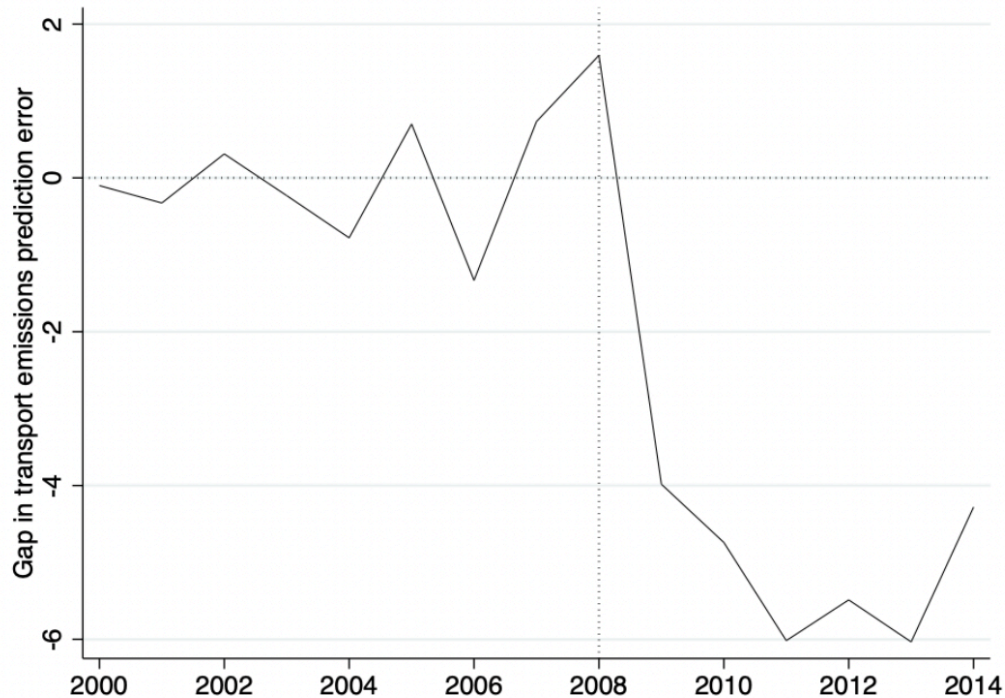


Figure 9. Gap in prediction error for the emissions from transport to its synthetic control. This graph displays the difference between the synthetic UK and real UK, using the synthetic values as the x-axis to better show deviations.

The following section discusses the robustness tests performed for both model performance and statistical significance. Because the SCM provides a matching estimator rather than a regression, we do not get standard errors on the parameter estimates, meaning that we have to run different analytical statistical significance tests. Various validity tests are conducted, which act as simulated significance tests. As an extra step, a simple statistical test for difference in means is conducted having extracted the treatment effect values from the graph above. Excel's z-test is used to get significance values, which are reported in the table below.

Z	3.83656059
P-value (one tail)	$6.24 \times 10^{-5}$
Z Critical one-tail	1.64485363
P-value (two-tail)	0.00012477
Z Critical two-tail	1.95996398

Table 5. Statistical significance test.

As we can tell from these values, there is a strong statistical significance with p-values well under the 0 - 0.05 desired range. The null hypothesis inputted into this calculation is that the effect is equal to 0. With this, we have confidence that the effect seen from this model is not random. This test is run only for analytical purposes, since the true validity tests are presented below in the more traditional placebo tests, which as mentioned, simulate significance tests.

## Robustness Tests

The SCM needs to be followed by some important robustness tests to test the validity of the results. For this, I perform a series of placebo studies, including a placebo in space, a placebo in time, and a "leave on out" test. The first one will confirm that our estimated effect for the UK is unusually large relative to the distribution of the estimate that we obtain when we apply the same analysis to the countries in the donor pool. Following the method and the reasoning from Abadie, Diamond, & Hainmueller (2010), Abadie and Gardeazabal (2003), and Bertrand, Duflo, and Mullainathan (2004), we ask the question of whether our results could be driven entirely by chance. If the treated unit were chosen at random, how likely is it that we would see results of

the same magnitude? This question is answered through the implementation of the in-space placebo test. In this test, I iteratively apply the SCM to estimate the effect of the UK CCA of 2008 in each of the countries in the dataset. By this, the UK is reassigned into the donor pool, and every country is selected as a treated unit individually, making it as if each country had passed a significant climate policy in 2008 instead of the UK. This inference can be better observed in the following figure.

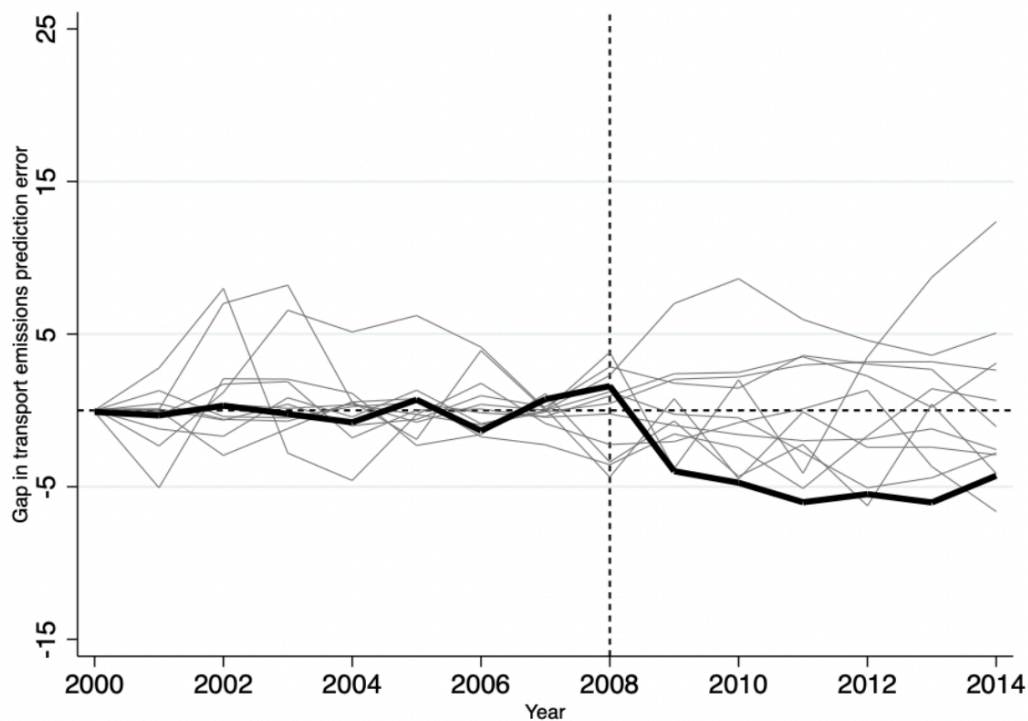


Figure 10. Placebo test. This figure shows the results of the in-space placebo test, showing the synthetic control gaps for different countries in the dataset, clearly showing the UK as an outlier.

As the figure makes apparent, the UK's estimated gap is unusually large relative to the distribution of the gaps for the states in the donor pool. This distinct path can be seen as the other units depicted show more of a messy trend, with some showing positive trends and others showing negative trends. The fact that the UK is an outlier aids in providing strength to the

significance of the effect calculated for the treatment. The negative effect on emissions from transport is definitely the lowest on the graph.

The second test focuses on the time factor. The placebo in time allows for us to build the SCM but feeding it a different date for the treatment. With this, not only the dotted line appears at a different time, but the model is trained on data previous to the new placebo date. This method allows us to gain more confidence in the result if we still see the effect only take place during the true time of implementation.

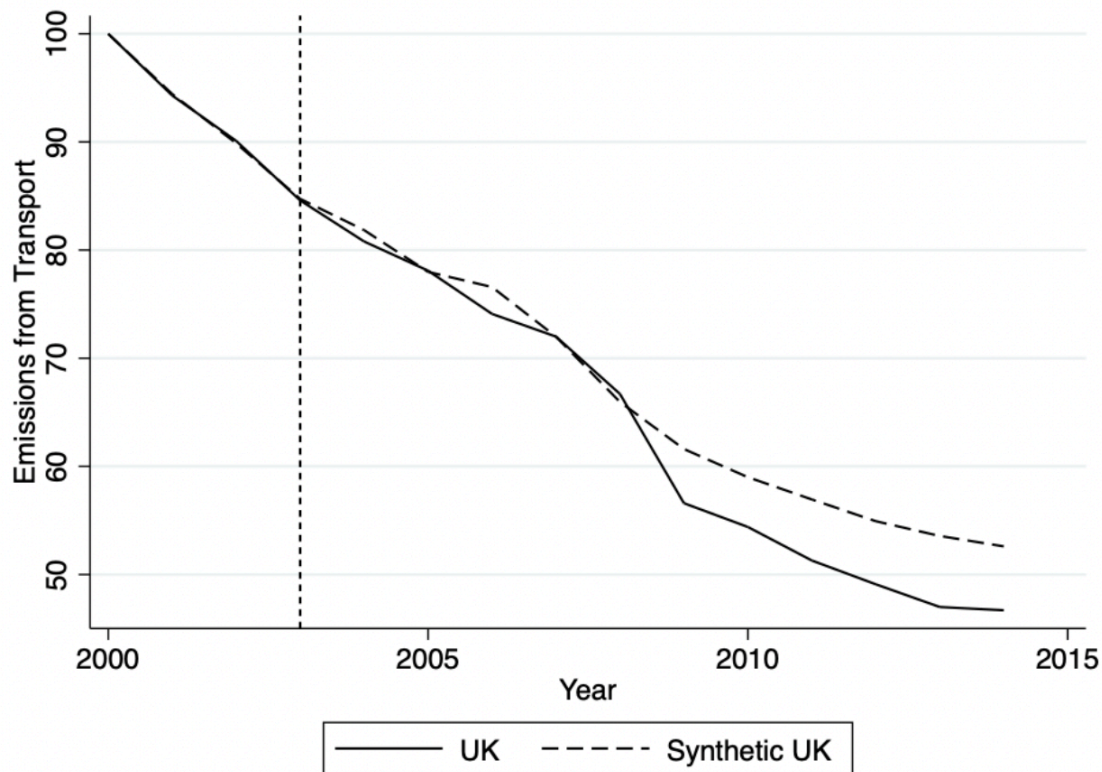


Figure 11. In-time placebo. This figure shows the result from the in-time placebo test. The model is fed a treatment period prior to the real one, in which we would expect no visible effect until the true treatment period.

The figure shows the fake date with the dotted line, and the treatment seems to be consistent. There is a difference with the fit compared to the original synthetic control output, but this is due to the difference in the years that the model was fit on. With this, we get additional

confirmation of the effect being valid, as the time factor did not significantly alter the results obtained.

Lastly, the synthetic control model is oftentimes preferred in comparative case study analyses due to the fact that it removes subjective researcher bias by choosing weights algorithmically and is transparent with the weights within the donor pool. This being said, we know from earlier in the results section that the synthetic control for the UK is built from Germany, France, Netherlands, Poland, and Finland. The "leave one out" test relies on removing

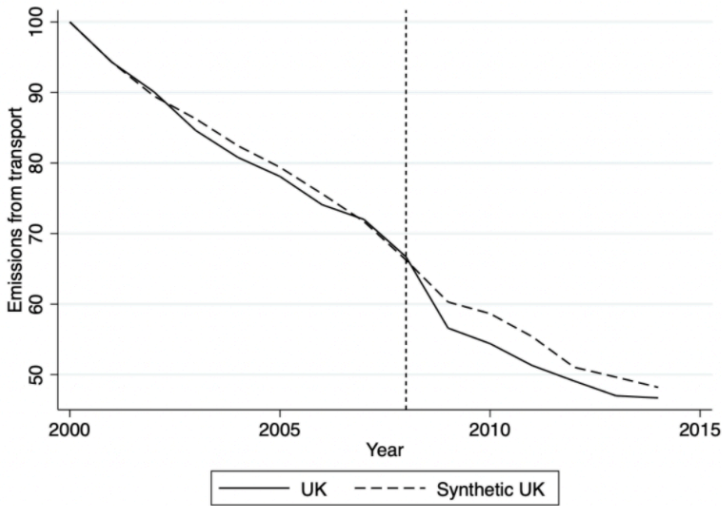


Figure 12. SCM Without Germany.

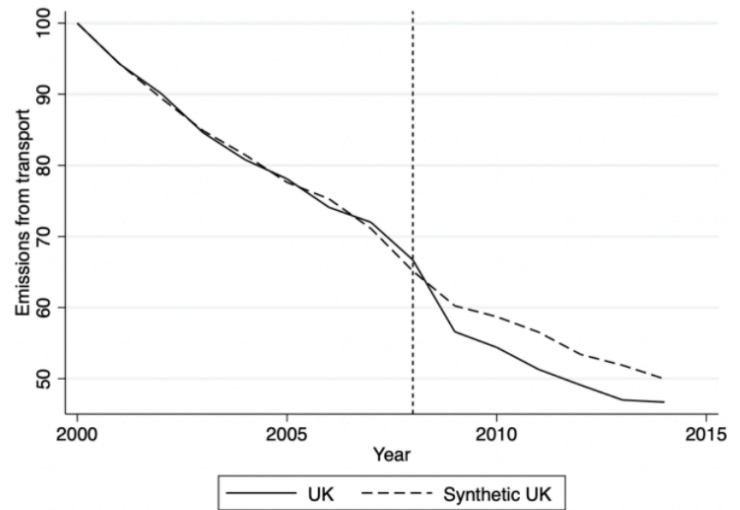


Figure 13. SCM Without France.

one by one each of the units that make up the synthetic control. In this way, I test if the results from the synthetic control are robust enough to withstand important changes in the donor pool. If the output were to be completely different in effect or magnitude, then the model is overly reliant on one unit, and the results seen are not very trustworthy. The following set of figures show the output from each of the SCM "leave one out" tests.

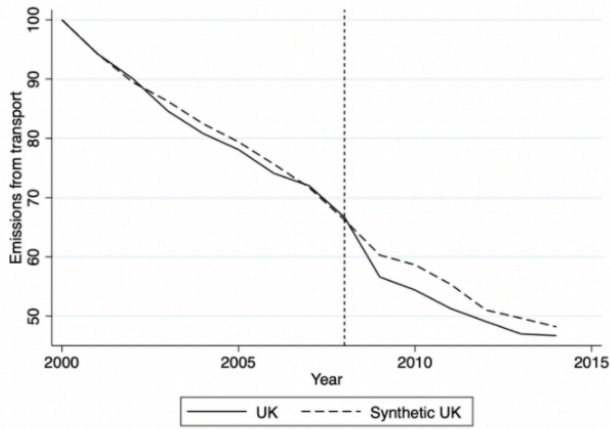


Figure 12. SCM Without Germany.

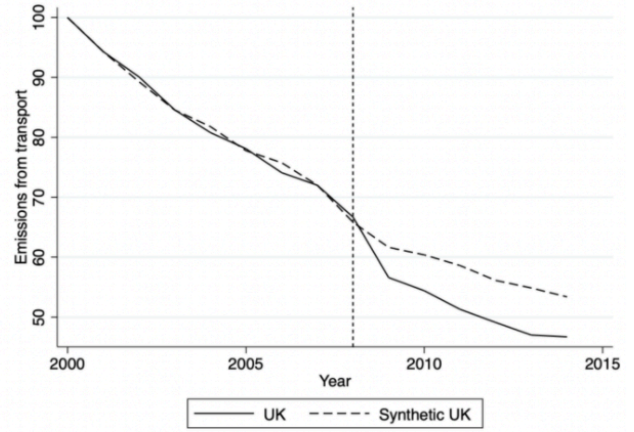


Figure 13. SCM Without Finland

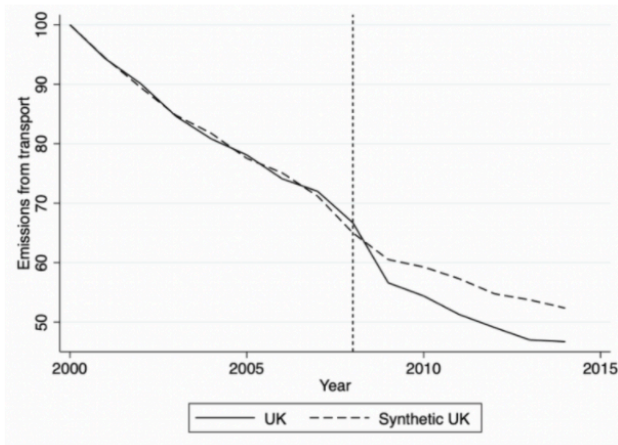


Figure 14. SCM Without Netherlands.

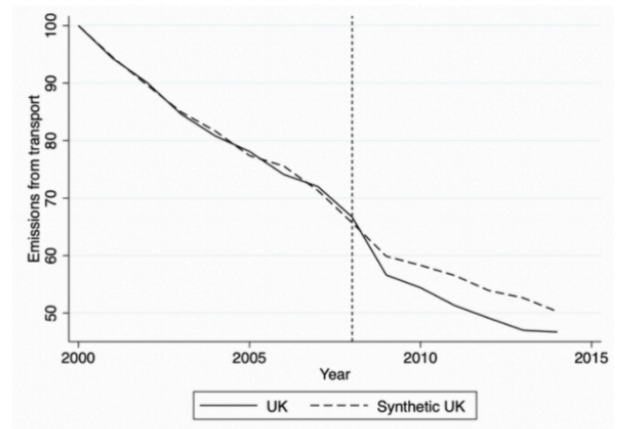


Figure 15. SCM Without Poland.

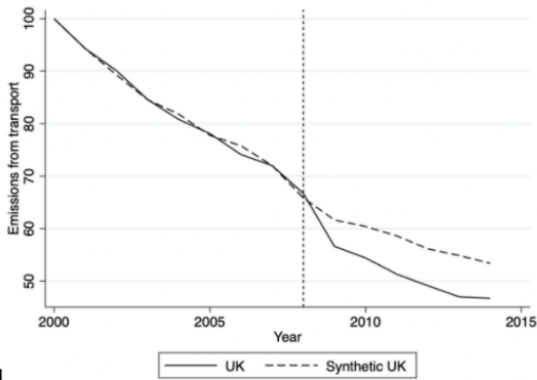


Figure 16. SCM Without Finland.

As the figures display, we work on the advantage the SCM offers in terms of transparent weights to build a robustness test that is not solely valid under specific data conditions, but rather

robust results that hold even when altering the synthetic control composition. This set of figures show the consistency of the estimation of the treatment effect across different donor pools.

## Discussion

Our results for effect on emissions from transport are highly encouraging since we have a significant negative effect due to the inception of the CCA. The fact that there is a negative effect on emissions signifies that the policy has actually aided in creating a positive effect in terms of reaching its goals. The policy targets many sectors, but the Low Carbon Transition Plan for Transportation has put forward some very specific policies aimed at improving air quality and reducing greenhouse gas emissions. The literature backs the claim that the CCA has been successful in creating a positive impact and creating a framework for further domestic policies worldwide to be crafted. These empirical results for transport emissions add to this idea, as the causal link is hashed out with the model, giving us statistical information validating the effect of the policy on emissions. Referring back to the literature, this can be expected due to several reasons. Firstly, air quality and pollution are a much more tangible problem than global warming. With this, I mean that the impacts of air pollution on human life are much more visible and directly quantifiable by simply looking out the window in a polluted city, counting deaths from poor air quality, or simply adding up the cost for hospitalizations. As behavioural economics tells us, the discounting factor that is broadly applied to the climate change issue is not as strong on this matter, as time scales are much shorter, and effects are more tangible (Dasgupta, 2008). Secondly, from an environmental perspective, air pollution is simpler to deal with since its atmospheric lifetime is relatively short. For example, NO<sub>x</sub>, one of the main pollutants from

vehicle engines, has an approximate lifetime of a day in the troposphere (Jacob, 1999). What this implies in terms of governance is that the effects of policy implementations should see short term responses. Thirdly, from an economic perspective, we need to consider a few things. The relative ease in which we can quantify the economic cost of air pollution would suggest that we can expect more prompt action taken from governments. Given international market trends, the cost for fuel efficiency, electric vehicles, and other clean sources of transport have dramatically dropped in price. This, plus additional incentives set in the CCA broadly, but specifically in the Low Carbon Transition Plan, allow us to predict emissions to have been reducing stemming from the policy. Fourth and lastly, international praise and the UK's global positioning as a climate leader and role model for other legally binding climate policies provide grounds for our expectation to be for a significant effect. In this case, the independence assumption is important to mention. Since the UK's CCA in 2008 has been shown to be innovative and novel, we have a strong case for this assumption to hold in the short term. However, as time progresses, other European states have also developed climate policies tackling emissions from all sectors. It is important to keep in mind that the validity of this assumption is not constant over time, with the notable mention of the Paris agreement in 2016, which can compromise the effectiveness of this estimation in replication studies, including more and newer data.

On the other hand, the analysis of CO<sub>2</sub> emissions did not yield the same type of conclusions. Conversely, our analysis suggests that climate policy has had little to no effect in terms of reducing CO<sub>2</sub> emissions. However, as seen in figure X, carbon emissions have been decreasing significantly over the years. Comparing this issue to air pollution might be problematic, as the timescales and amounts produced are vastly different. One of the main

reasons for these results is one of the major threats to the assumptions of the SCM. The spillover assumption and the independence assumptions here might be at risk. For one, carbon emissions have been directly tackled for decades before the CCA was ever enacted. The independence assumption deals with the fact that there is a problem if the donor pool has received similar treatment in the studied period. The case for CO<sub>2</sub> is complicated because of the wide ways that indicator can be approached. Given that the assumptions do not hold as strongly in this case, we want to be precarious with the results for CO<sub>2</sub> emissions, but attribute the decreasing levels to external factors to the policy, such as the lowering cost of alternative solutions, the rise of renewables, changes in consumer behaviour, social activism, technological developments, and more. For more specificity, emissions in 2011 saw a steep reduction due to a warm winter, the reopening of a nuclear plant in Southern England, and the economic slowdown (Bowen, 2014).

## Policy Implications & Learnings

Based on evidence from the literature and the study results, one thing has become apparent. Tackling air pollution with a policy like the CCA and the respective Low Carbon Transition Plan has been effective. The trend is evident from (figure where I present the line graph) and is backed by the literature (Department for Environment Food & Rural Affairs, 2018). As an exception, ozone seems to be the only air pollutant that has not shown signs of decreasing. More research on the types of atmospheric regimes is needed to address ozone reduction effectively. Focusing on the political lens, the political debate on climate change has been transformed into a topic of international importance, the UK's global position has been raised, and political consensus across parties on climate has prevailed. All of these have been

points in which the policy has been successful, and to maintain success should continue to happen. Focusing on the economic aspect, the power sector has also been transformed, and the country has been successful in maintaining GDP growth while lowering carbon emissions (Fankhauser et al., 2018). This decoupling of the carbon emissions and GDP is a significant factor in being able to sustain policy implementation over time and provides hope for it to continue down the same path. The success that the CCA has brought along regarding energy transition has been recognized, but more work needs to be done to ensure progress does not stagnate.

Some of the main ideas extracted from this study are on the aspects that have worked in generating tangible reductions in emissions, as estimated by the SCM. Firstly, The role of the CCC is crucial for policy delivery and evidence-based decision making, which is why having a strong independent body is critical for success (Fankhauser et al., 2018). Secondly, there needs to be an economy-wide intervention, setting multiple targets at different time scales providing a clear direction and conserving capacity to modify and amend long term objectives (Fankhauser et al., 2018). Thirdly, we have the core of the Climate Change Act. Climate law needs to contain clear duties and responsibilities to all areas of government and sectors of the economy. By making this policy legally binding, there is more of an obligation to comply with set targets and be transparent in the process. Lastly, mandatory monitoring and accountability have shown to motivate action and keep all sections of government on track.

Looking forward to implications for policymakers, there is a need to address some of the weaknesses of the policy, backed by literature and the fact that no causal link was found between the policy and broad CO<sub>2</sub> emission reductions. Fankhauser, Averchenkova, and Finnegan (2018)

identified a problem with uneven buy-in across government sectors that needs to be addressed to better perform in emission reductions. This 2018 paper also discusses the need to readdress and revisit some of the 5-year goals, and to strengthen the power of the CCC, to maintain the government accountable to its own plan, and subscription to the Paris Agreement, which mostly works together well with the CCA.

## Conclusion

This paper finds significant results for a negative effect on emissions from transport. The significant effect has shown that the policy has directly impacted the emissions from transport in a socially beneficial way. The indicator used in the model measures VOCs, NO<sub>x</sub>, and PM<sub>10</sub>, which are all harmful to human health and participants in some of the biggest air pollution problems in cities. The Low Carbon Transition Plan has created policies for the following purposes: improving fuel efficiency, supporting low carbon vehicles, research into future fuels, helping people choose low carbon transport options, limits on international aviation and shipping emissions and securing oil required during the energy transition period. All of these points have resulted in the policy having a positive effect on reducing emissions. Although the signs are mostly positive and reinforce the idea of continuing to use this policy as a model globally, work still needs to be done to continue to reduce harmful pollutants from transport and deal with air quality issues such as ozone and smog.

Adversely, this study finds no strong causal links between the CCA and a reduction in CO<sub>2</sub> emissions. Given constraints in data, threatened assumptions, and no discernible trend, more research into this causal link is recommended. CO<sub>2</sub> emissions have been in decline, which,

according to the literature, is partly to do with climate policy and external factors, but clear causal links are still mostly lacking in the literature. This is understandable given the complexity of the topic and the scale of the issue.

As ratified by Lorenzoni & Benson (2014) and the Grantham Research Institute on Climate Change and the Environment (2010), the UK has taken on a massive challenge to reduce emissions on such a broad scale. This broad evaluation finds a positive advancement towards long term goals as emissions have decreased in absolute terms. Additionally, the political drive shown by the government to sustain these long term projects has proven to be essential. The economy has continued to grow even while policies are being implemented, and public support is high for climate initiatives, with over two-thirds of Britons believing climate change is a “serious problem” and “needs to be prioritized” by the government (IPSOS MORI, 2020).

More studies are needed for assessing the external validity on a global scale. Additionally, this paper recommends further research into the effect of policies on CO<sub>2</sub> direct emissions and concentrations. Lastly, more research is recommended into the interactions between international climate policies and local domestic policies. Causality has become continuously harder to disentangle, but complex system studies are suggested to analyze the reach and effectiveness of this compound layering of policymaking.

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## Appendix

Link to dataset:

<https://drive.google.com/file/d/1oQkO6A5Qre2HOPo2pVwM8ZBsogsElm-i/view?usp=sharing>

Link to full code:

<https://gist.github.com/Aaronmoralesschildrick/69a94f43f74d163db1f4cc7fe488e36c>

HC/LO table:

Link to sheets with complete rubric of each of the HCs/LOs:

[https://docs.google.com/spreadsheets/d/1nVa98hBGIMA0zytq4ALfsoV3NHH3NGI-coPaPkP1V\\_w/edit#gid=1175800346](https://docs.google.com/spreadsheets/d/1nVa98hBGIMA0zytq4ALfsoV3NHH3NGI-coPaPkP1V_w/edit#gid=1175800346)

Name	Description of application
HCs	
(1)Professionalism	This paper is handled in a very professional manner. I make use of field-specific ways of formatting tables, writing figure captions, presenting the abstract, headers, table of contents, appendix, and more. I also make use of the proper APA guidelines for citations (list and in-text), and typography. I also present my thoughts and ideas in a formal academic way, sticking to the professionalism guidelines expected from a project of this magnitude. As I further explain in the Capstone specific LOs, I carried this project professionally from its very start, paying close attention to feedback, research, planning architecture, and connections with my advisor, peers, and experts. I

	<p>convey my work professionally, and I did a fantastic job of sticking to guidelines and making the paper look neat and professional.</p>
(2)Source quality	<p>I made use of a wide variety of sources and made sure they were of substantial quality. The reference list includes sources from many different types. Namely, I make use of peer reviewed articles, scholarly papers, official government documents, reports on the international level, databases, and popular media articles. The reason for using this specific combination of sources lies in the nature of the paper and the method. In order to get at the thorny aspects of running my model, I wanted to be sure to be following best practices and guidelines set in other papers with similar methods. I make use of the databases for my dataset and the model. I make use of reports and scholarly paper to be sure to have a solid understanding of the context and a good base for my literature review. As the bibliography reveals, I heavily relied on academic papers, and high-quality publishing institutions for my facts, as well as for my data.</p>
(3)Evidence-based	<p>In this paper, evidence is used in two main forms. For one, we have evidence from the literature, as I carefully selected the best papers and research studies that provide evidence for some of the claims and assumptions made in the paper. This is all part of generating a strong understanding on the topic, not only for me, but for the reader as well. Secondly, I make use of the evidence provided by my own empirical work. I make use of my model and the dataset I compiled to draw evidence for the effectiveness of the CCA in two different outcomes. I think that in both cases,</p>

	<p>evidence is used in a mindful manner, and its communication is clear and compelling. I am referring specifically to using evidence to make claims throughout the literature review which is cited appropriately, and to my results guiding my result, discussion, and policy implication sections.</p>
(4)Induction	<p>The results from this study (specifically the outputs of the model) are a complicated form of inductive principles. The model attempts to provide a conclusion from evidence (data) and premises (assumptions) from a question that is not straightforward. Inductive reasoning is used to construct the study and provide an answer to the impact evaluation question. The design of this paper was always keeping in mind the inductive skills and requirements. Specifically, the estimates provided by the model are attempting to induce the state of the UK in a world without the treatment. This is crucial and provides us with a meaningful analysis on climate policy in Europe.</p>
(5)Thesis	<p>Although a specific thesis statement is not written in one line, I follow the thesis that the CCA did have an impact in reducing emissions. This can also be seen as a type of thesis statement or hypothesis. The paper follows through with this idea, and arrives at a conclusion that is directly linked with how these emissions were lowered and its causal links to the policy.</p>
(6)Composition	<p>This paper is well written, and makes detailed explanations without being redundant. I wrote the paper in a clear way, and followed the writing guidelines for an academic paper. I wrote this paper parsimoniously and made sure to be simple and direct with</p>

	<p>my communication.</p>
<p>(7)Right problem</p>	<p>I identify the problem from the beginning of the paper and expand on this question through till the conclusions. I characterize the problem in an exhaustive manner, and also explain it very punctually. This can be seen in the abstract, justification, and introduction more broadly. I also make additional comments on the relevance of this problem, providing the reader with my motivation for this project, and the need for having better evaluations of environmental policies.</p>
<p>(8)Break it down</p>	<p>During the literature review, I break down the problem into its most relevant and important pieces. The table of content shows this in a very simple way, where I split the topics into smaller and more tractable pieces and areas of study. For this project, “break it down” was very relevant in almost every aspect of the paper, and this HC was used extensively. Examples include breaking down the environmental issues into smaller categories, which were all explored in the literature review. This same pattern occurred when it comes to climate policy, and analyzing the components and benefits of selecting the synthetic control.</p>
<p>(9)Communication Design</p>	<p>I make sure to have a proper design to ensure maximum readability. Targeting the principle of compatibility, I make sure that all of the graphs, tables, and figures make sense in their positioning, as well as their references from the text, allowing the reader to grasp the message more effectively, without having to lose time or notion of the paper by looking for figures or tables. I also made sure to make my paper look as professional as I could to account for field experts and new readers.</p>

(10)Self-awareness	For this project, I had to use this LO to be aware that I do not like to work under extremely tight deadlines, pushing me to get things done in advance to be able to have more time to think and polish my paper. I am also aware of the fact that making edits and creating whole new sections of work takes a long time, leading myself to not fall into thinking I have more time than I do. The awareness of myself and my specific ways of working have helped me develop this capstone as I have so far. This HC is very relevant in my description of the capstone-specific LOs.
(11)Context	I provide ample context for the topics of interest, and also situate the specific CCA into context with other climate policies. I also make use of this LO in the literature review for all sections, including context on modelling, climate, and climate policy. I identify the relevant aspects of each of these topics, and make use of an appropriate amount of context for a non-specialized university student to fully comprehend my paper. I also moderate the context provided as it is not meant to overpower the main sections of this paper.
(12)Organization	This paper is organized in a legible and logical way. Following the scientific method pretty much by the rules, I make a paper that starts with an abstract and takes the reader through the process, providing key information on the topic and methods, and results and implications. The organization used during the entire project is also explained further in the Capstone-specific LOs, but even this appendix table is organized by HCs and LOs for better visibility.
(13)Bias identification	I make sure to highlight the importance of identifying bias in order to be able to tackle

	<p>it. In the section where I specify the model, I also bring up how this model takes biases into account. By mentioning researcher bias, I have made it clear that a problem exists, among many others when developing this type of research.</p>
(14)Bias mitigation	<p>The selection of the SMC, allows me to mitigate for much of the bias inherent to other research methods, such as researcher bias, which the SCM precludes. I make sure to follow the guidelines for using the method to avoid running into confirmation bias as well, as the model brings up weights automatically, not designated by the researcher. The way in which the model works, allows the researcher to have no control over units into the composition of the synthetic control. This prevents all types of biases, and works well when studying a complex issue such as climate policy.</p>
(15)Dataviz	<p>My visualizations are informative and clean. I include axis names, clear values, and titles in the figure captions. The captions for the figures explain what we see in the figure, as well as pointing out some of the most salient factors.</p>
(16)Modelling	<p>The SCM is chosen to be the model for this paper. The outputs and the creation of the model all fall under this LO. Recognizing the importance of modelling in this research project, I make sure to address how this model helps us by creating a synthetic counterfactual to compare treatment and control.</p>
(17)Estimation	<p>I come up with an estimation of the impact the CCA had on two different outcomes. This HC was used to come up with numeric values as displayed in the graphs. The SCM provides an estimate of the values that the UK would have had if the policy had</p>

	<p>not been enacted. This entire paper is based on this estimation, making the HC one of the most important skills needed for mme to develop this analysis.</p>
(18)Variables	<p>I make a clear account of all of the variables being considered and explain them in depth. I look at different relationships between variables, and explain why these are the variables I selected, With regards to the outcome variables, I made sure to explain how these numbers are attained, and seek to leverage this understanding to draw conclusions.</p>
(19)Levels of analysis	<p>I make use of levels of analysis in several different points in the paper. For one, I talk about climate policy in different levels to more clearly articulate and situate the CCA. Levels of analysis is also a crucial HC, and as mentioned already in this appendix, has been used to explain the way climate policy works across levels of analysis. I look into policy on a global scale, and tackle it right down the levels list to domestic climate policy.</p>
(20)Responsibility	<p>I made sure to comply with all deadlines in making this project. I have been accountable for my own work and have attended meetings, classes, and sessions when necessary. I have been responsible for making my paper as good as I can. I have proven throughout these past 2 years that I have acted responsibly regarding this paper and meeting its deadlines. This HC is also highly relevant in my #ownership tag, and in my #qualit deliverables one as well.</p>

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LOs

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#ss154 data

This LO required me to identify various data structures and use appropriate data to answer research questions. For this project, I would say that the application of this LO might have been one of the toughest, but also one that I am very content with. Countless hours were spent in the identification part of this LO. I looked for appropriate datasets and data structures to fit into my desired SCM method. After looking at countless datasets, I had to come up with a tough choice, but I ended up deciding to construct my own dataset using high quality official sources. Since the SCM requires data from a large donor pool to perform well, integrating data across specified covariates was a challenge. I compiled a single dataset on my own to be able to get the values and variables I am interested in measuring, and using for the model. This took a surprising amount of time, and deep knowledge of #data was required for me to be able to do this effectively. Not only did I consider the sources of data, but the quality, timeframe, specific units, and structure. I also use data to illustrate much of the context, and perform descriptive statistics to deliver a more powerful background. My dataset is linked in the appendix in the appropriate format, namely, a panel data including all of the European zone, showing data across all of the variables specified in the data section of the paper. My deep knowledge allowed me to decide that no existing dataset was a perfect fit for my research, and led me to develop my own, resulting in one of the hardest aspects of this project.

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#Ss154 causaleffect	<p>This LO required me to accurately apply methodology to elicit causal effects. This is one of the central LOs from this paper. I focused on finding the necessary data and building the best model, according to specific strengths and weaknesses of modelling techniques to allow me to establish causality, rather than a correlation. In finding the causal effect, I first narrowed down my topic of interest, to focus on a specific treatment (CCA 2008). For this case I selected the SCM to create a synthetic counterfactual, for me to solve the fundamental problem of causal inference, giving me a way to compare a treatment with a control unit. This LO is not only referring to the discussion of the causal effect of the policy, but also my understanding of causality as a whole. I made sure to tackle this research question from the start by estimating the effect of the policy on two separate outcomes (transport emissions and total CO<sub>2</sub>). In the discussion, I accurately identify what the causal effect means from a practical standpoint, and I further discuss implications of the findings given my causal analysis. The discussion is richer and more deep on transport emissions, since the causal effect is more clear, providing us more ground for making inferences and extracting meaning from the model results. Lastly, I am extremely critical when it comes to my analysis on limitations of the model itself. I mention threats to validity, and factors to take into consideration as results are interpreted.</p>
#Ss154 appliedeconometrics	<p>As mentioned in the LO description, I accurately identify and apply an appropriate quantitative econometric method for my given research question. Initially, I had to choose a model with which to tackle the problem. I discuss in great length in the</p>

	<p>Methods section my reasoning and my justification for selecting the SCM. I provide a thorough and thoughtful analysis of why this model was appropriate for tackling the problem. I go into detail again in the methods section on the assumptions, and I also identify potential limitations given the assumptions in my particular topic, being very transparent with the process. Directly on the application of the model, the pre-treatment fit of the model on the data is very good, which indicated a successful application of the model. As far as this research question, I employ this causal inference model to arrive at conclusions at a national level, which is also why the SCM does a good job. As a second aspect of this LO, I walk the reader through the results section, providing evidence, context, and accurate interpretation of the results as I go. As discussed in the data section already, I built an appropriate dataset allowing me to tackle the problem through what I consider to be one of the best methods for quasi-experimental studies.</p>
<p>#Ss154 statisticalvalidity</p>	<p>Statistical validity is one of the cores of this paper. The entire analysis depends on the statistical validity tests. As discussed in detail in the paper, the SCM makes use of different robustness tests which are designed to test statistical validity. Initially, I make use of the in-space placebo test, which seeks to confirm there is a tangible difference stemming from the streatment period when compared to other units in the donor pool. As my paper shows, the UK is an outlier when it comes to emissions from transport. Secondly, I make use of the in-time placebo test, which is a statistical validity test regarding the effectiveness of the model to show the same causal impact</p>

even when the model is fed a different date. Thirdly, I use the “leave one out” placebo test, which runs the same model excluding each of the donor pool units that comprise the synthetic treated unit. These three tests are the main applications of the LO, and the main forms of application are as follows. First, I needed to comprehend the type of statistical tests needed to prove the utility of my estimates. Secondly, I needed to know how to code these tests up to be able to show the results in my paper, which I did by looking at reference papers, and seeking advice from classmates who have knowledge in this area. I also made use of a difference in means statistical test to further strengthen the argument, which points at a null hypothesis of being no significant difference, and an alternate hypothesis of a lower number of emissions in the actual data when compared to the model estimates.

#SS164

Economicinfluences

In the introduction of the paper, I look at the way environmental outcomes are affected and influenced by policy on multiple levels. To be clear, I make sure to include a comprehensive explanation of the state of climate policy, as well as looking at some of the most important scientific aspects regarding the issue. This led to the entire point and idea behind studying climate policy through the lens of causal inference, to see how policy is influencing environmental outcomes. This LO was very useful in framing my paper in a way that explains the relation between scientific factors, climate policy, and environmental outcomes. This LO was also useful when building the dataset and crafting the model specification, by identifying important influences on the outcomes and writing them down as variables.

<p>#Ns156</p> <p>Earthapplications</p>	<p>In this paper, this LO is used to evaluate solutions to environmental issues effectively.</p> <p>This is a broad LO, but as far as the evaluation aspect, this paper shows a very strong application of how a solution to an environmental problem is critically evaluated by rigorous scientific methods. In the introduction, I make sure to bring out the relevance of the context of my topic to the Earth system. I include in my literature review the essential aspects that the policy targets, which is ultimately the goal of analyzing the effectiveness of the policy. I also make graphs in this first section to show a time-series of how important environmental variables have changed over time.</p> <p>Getting more into the evaluation, I use econometrics to identify a causal link stemming from the policy to the reduction in transport emissions. These results, coupled with research, input from other scientific papers, and political evaluations of the policy, result in all of the consequences discussed in the discussion and policy implications. Once this has been evaluated, I make sure to mention recommendations of how environmental impacts can be diminished even further contributing to the environmental reasons talked about in the literature review. Although a policy is not a scientific intervention, a policy of this magnitude is a solid social solution to the environmental problem of CO<sub>2</sub> and transport emissions.</p>
<p>#IL181</p> <p>Policy-evaluation</p>	<p>Following the guidelines set for this LO, I took an entire section of the literature review to outline the Climate Change Act of 2008. Essential to a strong application, is a clear and meaningful description of the policy and its instruments, which I provide in a clear way. I look at the specific scope of the policy, by providing context</p>

beforehand on the interaction of policies at different levels, and scoping the conversation down into the target of my paper. I speak about scope, details, and instruments used and further discuss its importance and relevance on a global scale. I then proceed to define the variables I will be looking into throughout the paper, allowing me to keep track and focus of the change over time. I go beyond the normal usage of the LO, and make use of one of the most recent and best causal inference models available to quantitatively evaluate policy. This is on top of extensive research and backing my points with high-level policy evaluations. After this evaluation part, I identify weaknesses and points that require further research. I conclude the paper with a discussion and a policy recommendation which incorporates my findings into an informed critique and proposals for the future.

#Ss146

Governanceeffectivene  
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This LO is introduced in the literature review, as I set up the notion of government policies, and outline the intervention. This identification and explanation is the first step of using the LO. I do a good job in providing context, and allowing for the reader to understand the policy and the current state of the main variables. This LO is truly drilled down in the discussion and the policy implications section, where I look at evidence from different sources and from my own analysis to conclude on the state of governance effectiveness. My analysis outlines the way the plan has been effective in tackling emissions from transport, and signals out some of the main factors that have led to this result. Specifically, I point out salient aspects of the governance plan that have work and are recommended to be replicated globally, and it also shows weak

	<p>spots and potential work needed. I evaluate the effectiveness of government in implementing policies to achieve the environmental goals through the SCM and provide adequate discussions given the results.</p>
#Ss154 Specification	<p>I use extensive economic reasoning to justify the covariates used in the models for each outcome, which are all based on relevant high-quality. I based my work on countless papers looking at synthetic control applications, and more specifically, causal inference for climate outcomes. This LO is used extensively as I build out the arguments and the main reasons for selecting my specific methodology. More specifically, I looked at the assumptions thoroughly explained in the methodology, and made sure to highlight the value in having a model to deal with precluding extrapolation, removing subjective researcher bias, showing transparency of counterfactual, and sparsity. I also detail the reasons and explain the covariates used in the model to further specify how my methods are lined up appropriately. I also look at trends, and make use of the tables comparing the synthetic outcome to the real data to show similar trends in the pre-treatment period. The end result is the individual model used to achieve the SCM outputs, and can be more carefully seen in the code linked.</p>
#Ownership	<p>This LO reflects the ability to demonstrate ownership and stewardship of the Capstone project. During this whole process, I kept established commitments, took responsibility for the development of the project, demonstrated agency, and was resilient to challenges. I allocated a specific amount of work to capstone at the</p>

	<p>beginning of every week, making estimations based on my to-do list, leaving time for improving, and building on feedback. As further mentioned in the Planning architecture LO, I used Notion rigorously, allowing me to be in full control of my project. I have been consistently effortful throughout this project, as I have strived to stay ahead of time, as my Capstone adviser always recommended. I am extremely grateful, as it allowed me to have a much better focus, and more time to polish my paper this semester. When obstacles have come up, I have found good ways to solve them by approaching my network, building on high-quality feedback, and learning on my own from web resources.</p>
<p>#Qualitydeliverables</p>	<p>Throughout the entire Capstone process, I have made sure to always deliver quality products in time. For all of my deliveries over the past two years, I made sure to comply with all of the requirements, and even went beyond most of the times, simply because I knew early work would pay off in these late stages. For this final capstone specifically, the paper is professionally presented and has adhered to APA guidelines strictly, including in-text citations, full reference list, formatting, and language. The paper is modelled after similar research papers in my interest field, and I make sure to use the most updated econometric models and information to make the paper better in quality. Lastly, I reported results and estimates transparently, which can be a difficult topic in academia, as researcher bias is not uncommon. I made both my code and original datasets available for replication in the appendix, for my work to be evaluated and tested if needed or desired, as a standard practice.</p>

#Planning architecture	<p>During my entire Capstone experience, I have been focused on finding the best fitting systems for me to progress on my project effectively. Of course these have changed over time, since I had no idea of what it took to complete a project of this magnitude at the beginning of this project starting CP191. I would say I have tried and tested different types of structures and systems, but always in advance, and paying close attention to successes and failures along the way. Initially, I had big hopes and expectations regarding my performance, and capacity for accomplishing goals in a short period of time. I started off by making use of Asana, an app for project development and teamwork. I found this to be helpful on an early stage to organize my thinking, and allow me to easily pivot and change my project as I saw fit. After a while, I realized that as I gained more clarity on the scope of my project, I was using Asana less and less, which made me never open the app. I needed to change my strategy. I then became a part of a capstone working group with some classmates, and we were posting and monitoring our advances as the days went on. Ultimately, I became very fond of using Notion, not only for capostone but for my daily activities as well. As the project got more granular, I swapped to a very punctual to do list of items, which in notion, allows you to easily add and drag items to different columns, such as “high priority”, “recently completed”, “fully polished”, and “urgent”. This system allowed me to have a clear idea of what needed to be done, as well as being very visible as I would access this page on a daily basis.</p>
#feedback	<p>Feedback has been an essential aspect of this project. I would say that if I had not</p>

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used this LO, this project would have never been completed. Initially, I relied on my Capstone Seminar professors for initial feedback. In this process, my classmates played a crucial role in helping me define my topic, narrow down the scope, and pushed me to identify clear paths for me to pursue in the capstone. It was at this stage where I identified which variables I wanted to look at, and realized that building a dataset for the purposes of my project was not only a positive thing, but necessary. In this space I would like to highlight feedback I received from professor Aslim and professor Morgan, since they have helped me develop this project into what it is today. I listened intently, and read carefully all pieces of feedback and integrated them into my to do list above mentioned to take decisive action to fix. My classmates and especially my friends, have also had a footprint in this project, being an essential tool for perspective and quality of my writing. Part of this LO is also providing feedback, which I did whenever requested, and offered to do so on several occasions. I engaged in this during the first year of capstone as part of the assignments, and later through my capstone group, and my friends' paper.

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