International Climate Policy and Renewable Energy Consumption*

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Abstract

Has the Kyoto Protocol (KP) induced renewable energy consumption ? Increasing the share of renewable energy consumption in final energy consumption is vital for reducing green house gas emissions thus limiting global temperature rise to less than 2°C. In this paper, I examine the causal impact of the KP on renewable energy consumption using the Generalized Synthetic Control Method (GSCM). The GSCM enables me to compare the renewable energy consumption of industrialized countries with what would have happened in the absence of the KP (the counterfactual scenario) whiles allowing for multiple treated units, variable treatment dates and easy inference. I find that the KP led to an increase in renewable energy consumption. I also show that the potential mechanisms through which this operates are increased expenditure on renewable energy research, development and demonstration as well as increased investment in renewable energy installed capacity.

Keywords: International climate policy, Kyoto Protocol, Renewable energy , Generalized synthetic control
JEL classification codes:C2,F53, Q40, Q56 Q58

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1 Introduction

Climate change is considered one of the greatest threats to the economic and social resilience of many countries. There has been substantial increase in temperatures and extreme weather events globally in the past half century. This is mainly due to the sustained increase in well-mixed greenhouse gas (GHG) concentrations caused by human activities (IPCC, 2021). In view of this, numerous international agreements and policies have been enacted with the goal to limit GHG emissions. One of which is the Kyoto protocol (KP). The KP placed binding on the so-called Annex-B (industrialized) countries to reduce their emissions to an average of 5% below 1990 levels over the first commitment period (United Nations, 1998).[1]

At the heart of the United Nations' Framework Convention on Climate Change (UNFCCC) (which the KP operationalized) is the adoption and implementation of climate mitigation policies. An increase in renewable energy consumption constitutes an important part of climate mitigation policies. An increased deployment of renewable energy can contribute to achieving the emission reductions needed to limit global temperature rise to less than 2°C (Gielen et al., 2015; IRENA and IEA, 2017). This is because fossil fuel consumption accounts for the majority of global anthropogenic GHG emissions (Edenhofer et al., 2011; Gielen et al., 2015).

In this paper, I examine the impact of KP on renewable energy consumption. Examining the causal impact of KP on green growth is far from trivial. First, there is obvious selection into treatment: Annex B countries are mostly industrialized and transition economies in the 1990s which makes them significantly different from non- Annex B countries. Secondly, the KP allowed Annex B countries to meet the targets mainly through national measures and three (3) flexible market-based mechanisms which allows cooperation with developing countries: International Emissions Trading (IET), Joint implementation (JI) and Clean Development Mechanism (CDM). Most importantly, the CDM allows Annex B countries to cooperate with non-Annex B countries to engage in a GHG emissions reductions project such as renewable energy electrification project. The CDM may lead to a higher renewable energy penetration in non-Annex B i.e., the renewable energy consumption of Annex B countries may remain stable or decline while it increases in non-Annex B due to the CDM. Therefore, the differences in renewable energy consumption between the two groups of countries is likely to overestimate the impact of the KP on renewable energy consumption.

To deal with the above issues, I employ the Generalized Synthetic Control Method (GSCM)

[1] 2008 to 2012

developed by Xu (2017). The GSCM is based on the original SCM (Abadie and Gardeazabal, 2003; Abadie et al., 2010) and uses a data driven approach to create a synthetic control that best reproduces the outcomes of the treated group in the pre-treatment period. An advantage of the GSCM over the original SCM is that it allows for multiple treated units and variable treatment periods. It also allows for classical inference because it provides uncertainty estimates such as the standard errors and confidence intervals.

I find that the KP led to 3.5 percentage points increase in the share of renewable energy in final energy consumption in countries that were legally bound by the KP. This result is robust to a set of robustness checks. I also find that the potential mechanisms through which this operates are increased expenditure on renewable energy research, development & demonstration and growth in net installed renewable energy capacity.

My paper contributes to the literature in two ways. First, to the best of my knowledge, this is the first study to examine the causal impact of the KP on renewable energy consumption. An increasing number of studies have examined the effectiveness of the KP in reducing GHG emissions. Most of them found that the KP led to a reduction of GHG emissions (Maamoun, 2019; Grunewald and Martinez-Zarzoso, 2016; Aichele and Felbermayr, 2013a) while Almer and Winkler (2017) found little or no effect of the KP on GHG emissions reduction. By focusing on renewable energy consumption, I provide evidence on one of the channels through which KP affected GHG emissions. Some studies also examined the effect of the KP on technology diffusion (Miyamoto and Takeuchi, 2019), trade flows (Aichele and Felbermayr, 2013b; Tran, 2021; Kim, 2016), carbon leakage (Aichele and Felbermayr, 2015, 2012). Second, I also examine the mechanisms through which the KP led to an increase in renewable energy consumption. This has policy implications for other climate policies such as the Paris Agreement where about 182 parties had included renewable energy components in their NDCs as of November 2021 (IRENA, 2022).

The rest of the paper is structured as follows. Section 2 describes the empirical strategy and data are while section 3 presents the empirical results. Section 4 investigates the potential mechanisms driving the results. Section 5 presents the results of robustness tests while section 6 concludes.

2 Methodology and Data

This section discusses the framework and data used in the study.

2.1 Empirical strategy

To assess the impact of the KP on renewable energy consumption, I use the GSCM proposed by Xu (2017). The GSCM provides a data driven approach to create a synthetic counterfactual using information from the pool of aggregate units not exposed to the intervention. The idea is similar to that of the SCM (Abadie and Gardeazabal, 2003; Abadie et al., 2010).

The GSCM however has some advantages over the SCM. First, it easily allows for multiple treatment units and different treatment periods simultaneously. This is important for this paper because the treatment date is varied. Second, it allows easily for classical inference because it provides uncertainty estimates such as the standard errors and confidence intervals.

2.1.1 Framework

The outcome of interest is expressed as:

$$Y_{jt} = \alpha_0 + \delta_{jt} Kyoto_{jt} + \beta X_{jt}^{'} + \lambda_{jt}^{'} f_{jt} + \epsilon_{jt} \tag{2.1}$$

Where Y_{jt} is the outcome of interest for country j at time t. $Kyoto_{jt}$ takes the value of 1 if country j at is legally bound by the KP time t and 0 otherwise. Following the existing literature, I the enforcement year as the treatment year, 2007 for Australia and 2005 for the others. X_{jt} is a (k × 1) vector of observed covariates, β is a (k × 1) vector of parameters, f is an (r × 1) vector of unobserved common factors which represents the time varying coefficients and λ_{jt} is an (r × 1) vector of factor loading which represents country specific intercepts. ϵ_{jt} is the error term for country j at time t.

The coefficient of interest is δ_{jt} which captures the treatment effect. Let Y_{jt}^{1} and $Y_{jt}0$ represent the outcome for country j at time t when $Kyoto_{jt}$ takes the value of 1 and 0 respectively. The treatment effect on the treated can be expressed as:

$$\delta_{jt} = Y_{jt}^{1} - Y_{jt}^{0}, \qquad t > T_0 \tag{2.2}$$

2.1.2 Formulation of counterfactual

The main challenge here is that Y_{jt}^0 (the counterfactual) is not observed when the KP was enforced. This counterfactual is therefore created from a pool countries that were not legally bound by the KP (comparison group). Let N_{tr} and N_{co} be the number of treated and comparison groups respectively, the outcome of a country in the pool of comparison group is expressed as follows:

$$Y_{jt} = \beta X_{jt}^{'} + \lambda_{jt}{}' f_{jt} + \epsilon_{jt} \tag{2.3}$$

Thus, the counterfactual outcome after combining all of the countries in the comparison group is expressed as:

$$Y_{co} = \beta X_{co}^{'} + F\Lambda_{co}^{'} + \epsilon_{co} \tag{2.4}$$

Where Y_{co} and ϵ_{co} are (T x N_{co}) matrices, X_{co} is a (T x N_{co} x k) matrix and Λ_{co} is (N_{co} x r) matrix. The identification of β, F and Λ_{co} requires all the factors to be normalized and orthogonal to each other.

The counterfactual, $\hat{Y}_{jt}^0$, is constructed in 3 steps.

1. The first step consists of estimating $\hat{\beta}$, $\hat{F}$ and $\hat{\Lambda_{co}}$ using interactive fixed-effects model (Bai, 2009).

2. The factor loadings, $\hat{\lambda}_j$, are estimated for each treated country are estimated in the second step. This is achieved via minimizing the mean squared prediction error (MSPE) of the outcome of the treated countries in the pre-treatment period.

3. Finally, $\hat{\beta}$, $\hat{F}$ and $\hat{\lambda}_j$ are used to construct the counterfactual.

Thus, the estimated average treatment effect on the treated (ATT) is given as:

$$A\hat{T}T_t = \frac{1}{N_{tr}} \sum_{i \in T} \left(Y_{jt}^1 - Y_{jt}^0 \right), \qquad t > T_0 \tag{2.5}$$

2.2 Data

The datasets used in the study spans from 1990 to 2012 covering 104 countries. The choice of the analysis period is based on the fact the first commitment period of the KP ended in 2012. There was an amendment after that which was not validated until October 2020. It is also uncertain whether the KP is still effective.

The main outcome variable of interest is renewable energy consumption as a percentage of final energy consumption (FEC) sourced from (World Bank, 2022). I also use renewable energy consumption per capita (KTOE per 1000 population) as the outcome variable in a robustness test. The renewable energy data comes from IEA (2022b) and the population data from (World Bank, 2022).

To test the mechanisms of the results, I use data on renewable energy research and development and installed renewable energy capacity sourced from IEA (2022a) and IEA (2022b) respectively. The definition of all the variables and their sources are provided in Table A.1 in Appendix A. Table A.2 presents the summary statistics of the variables used in the study.

3 Results

Table 1 summarises the average effect of the KP on renewable energy consumption. The first column shows the average treatment effect on the treated (ATT) without controlling for other variables while the second column accounts for other other variables that can influence renewable energy consumption. The control variables include real GDP per capita, the square of real GDP per capita,population growth and urban population (% of total population)

On average, renewable energy consumption increased in countries that ratified the KP compared to the business as usual (BAU) case i.e what would have happened in the absence of the KP. Specifically, the KP led to a 3.5 percentage points increase in the share of renewable energy in final energy consumption (FEC), on average.

The evolution of renewable energy consumption of the treated countries (red line) and the synthetic control countries (dashed black line) are shown in the top panel (panel a) of Figure 1. As it can be seen, the synthetic control mimics the trajectory of renewable energy consumption of the treatment group prior to the treatment year. Also, the consumption of renewable energy increased sharply after the treatment period in countries that are legally bound by the KP while it declined in the the BAU case (dashed black line).

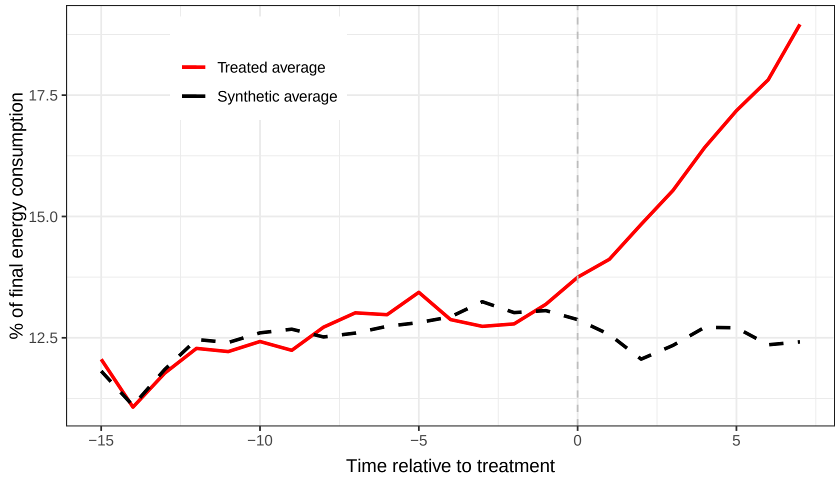
Panel b of Figure 1 shows the evolution of the gap (ATT) in renewable energy consumption between the treated and the synthetic control. The shaded area indicates the 95% confidence intervals. The figure indicates that there is no statistically significant effect of the KP on renewable energy consumption prior to the enactment of the KP. This again points towards the quality of the GSCM in making the synthetic control countries to reproduce the trajectory of the renewable energy consumption for the treated countries in the pre-treatment period. A positive effect on renewable energy consumption is found in all the post treatment period. Specifically, the ATT is positive but not significant in the first and second post treatment period. This however becomes significant from the third up to the sixth post treatment period. In addition, the magnitude of the average treatment effect increases and becomes less precisely estimated with time.

Panel c of Figure 1 shows the cumulative average treatment effect . The horizontal bars indicate the 95% confidence interval. A general increase in the cumulative point estimates is observed after the enactment of the KP. In particular, a positive and significant cumulative effect is observed in the 3rd, 4th, 5th and 6th years after the enactment of the KP. The cumulative effect of the KP on the share renewable energy (% of FEC), 6 years after its enactment amounts to 16 percentage points. Taken together, the results suggests that the KP had a positive effect on renewable energy consumption.

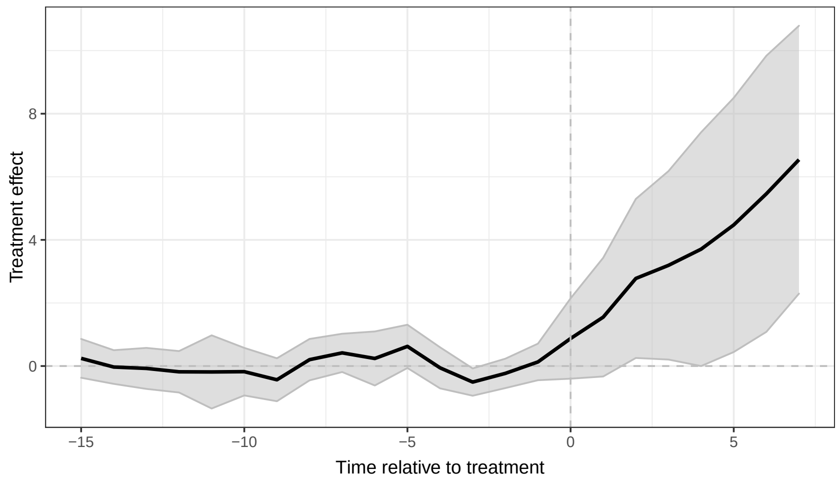
Table 1: Impact of KP on renewable energy consumption

	1	2
Kyoto	4.333***	3.547***
	(0.912)	(0.971)
Control variables		✓
Number of treated countries	25	25
Number of control countries	88	88
MSPE	1.4	1.1
Unobserved factors	2	2

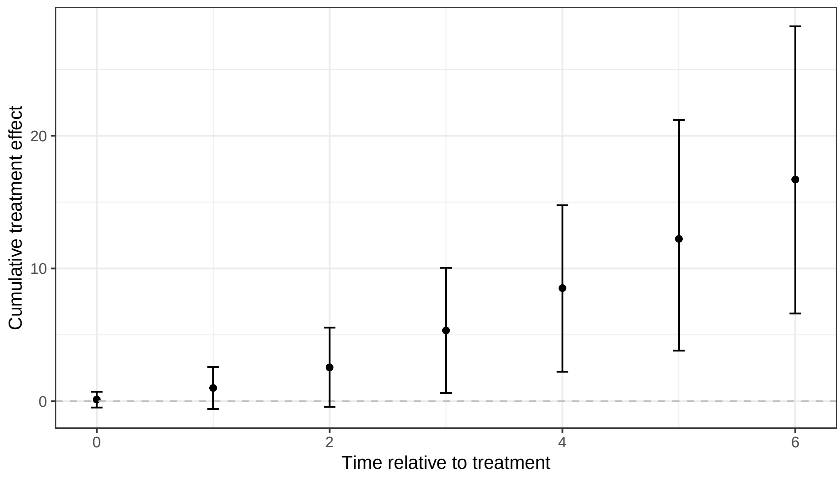
*Notes: The table presents the impact of KP on renewable energy consumption. Control variables include, real GDP per capita, the square of real GDP per capita,population growth and urban population (% of total population. Robust standard errors clustered at the country level are in parentheses. ***, **,* denotes 1%, 5% and 10% level of significance respectively.*



(a) Treated and synthetic control



(b) Average treatment effect on the treated (ATT)



(c) Cumulative treatment effect

Figure 1: **Impact of Kyoto Protocol on renewable energy consumption**

Notes: The figure shows the results of the impact of the Kyoto Protocol on renewable energy consumption using the generalized synthetic control method proposed by Xu (2017). Panel (a) shows the average renewable energy consumption (% of final energy consumption) for the treated countries and that of the synthetic controls. Panel (b) shows the evolution of the average treatment effect on the treated. The shaded gray area indicates the 95% confidence intervals. Panel (c) shows cumulative treatment effect of Kyoto Protocol on renewable energy consumption.The horizontal bars indicate the 95% confidence intervals.

4 Potential mechanisms

The results in the previous shows that the KP has led to an increase in renewable energy consumption. In this section I examine two channels through this is likely to occur.

4.1 Renewable energy research and development (RD & D)

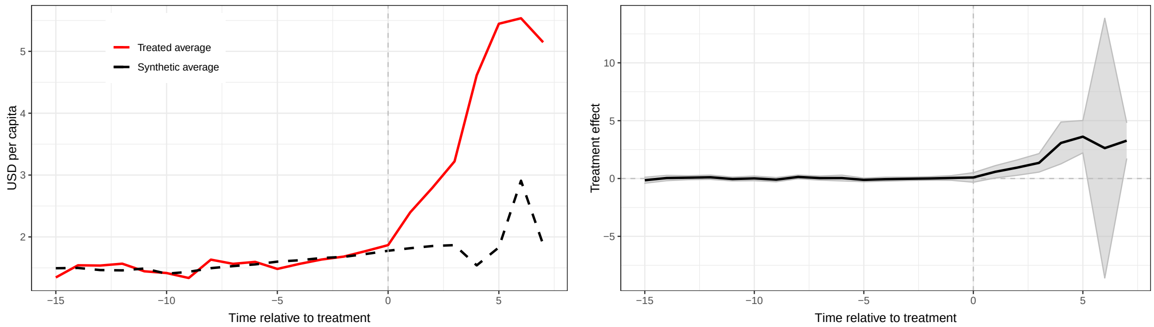
Th development of renewable energy technologies is vital to their deployment. Renewable energy RD&D activities have played a major role in the successful development and commercialization of a range of new renewable energy technologies in recent years (OECD). To examine this mechanism, I use data on renewable energy RD&D budgets(USD per capita) sourced from IEA (2022a) . IEA (2022a) collects this information from central or federal government budgets, and the budgets of state-owned companies. The results are shown in panel A of Figure 2. As can be seen, the evolution of average renewable energy RD&D budgets of synthetic control countries mimics that of the treated units. The dynamic average treatment effect suggests that the KP led to an increase in renewable energy RD&D expenditures.

4.2 Investment in renewable energy generating capacity

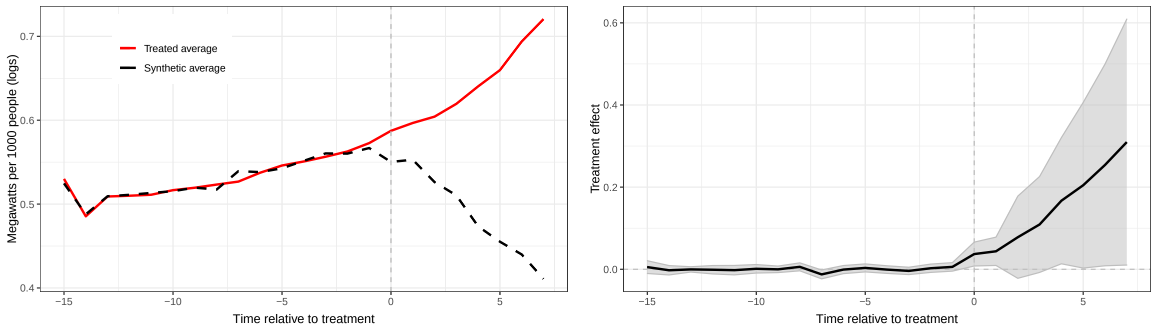
One of the potential ways the KP can lead to an increase in the share of renewable energy consumption in final energy consumption is investment in renewable energy generation capacity. To test this channel, I make use of data on net installed renewable capacity in Megawatts per 1000 people (in logs) sourced from IEA (2022b).[2]

The results are shown in panel b of Figure 2. Once again, the evolution of average renewable energy capacity of synthetic control countries mimics that of the treated units. The dynamic average treatment effect also suggests that the KP led to an increase in renewable energy generating capacity.

[2]The net maximum capacity is the maximum active power that can be supplied, continuously, with all plant running, at the point of outlet



(a) Impact of Kyoto Protocol on renewable energy research and development



(b) Impact of Kyoto Protocol on investment in renewable energy capacity

Figure 2: Mechanisms result

Notes: The figure shows the results of the impact of the Kyoto protocol on renewable energy research and development using the generalized synthetic control method proposed by Xu (2017). The shaded gray area indicates the 95% confidence intervals.

5 Robustness tests

In this section, I conduct a series of check to understand the robustness of the results presented in section 3.

5.1 Exclusion of CDM host countries

The CDM is a mechanism under the KP that allows countries that are legally bound by the KP to undertake GHG emissions reductions project such as renewable energy electrification project in developing countries in order to earn certified emission reduction credits, each equivalent to one tonne of CO_2. This suggests that the some of the units in the control group may actually be treated units. This shouldn't pose a problem because the GSCM creates the synthetic control group b to best reproduce the treated group in the period prior to the treatment. It can however be argued that the CDM host countries are more likely to constitute a large proportion of the counterfactual thus biasing the results. I therefore excluded, the top host countries of CDM projects, China, India, Brazil, Mexico, Vietnam, Malaysia and Indonesia from the control group. The average treatment effect is shown in column 1 of Table A.2. As can be seen, the effect are of similar magnitudes as those reported in column 2 of Table 1. The plots shown in panel a of Figure 2 are also similar to those obtained in the main results. This means that the the inclusion of these countries in the control group does not bias the results.

5.2 Exclusion of countries with limited commitments

Some of the treated countries such as Russia, Ukraine, Romania, Bulgaria, Poland and Czech Republic had limited commitment to reducing GHG emissions under the KP. It is likely that their inclusion in the analysis could underestimate the results. Therefore, I exclude these countries from the treated countries. The average treatment effect is shown in column 2 of Table A.2. Again, the effect are of similar magnitudes as those reported in column 2 of Table 1.

5.3 Exclusion of EU countries

The members of the European union are likely to more incentivized to shift to a cleaner energy sources in order to reduce their GHG emissions than other countries that are bounded by the KP because they have other commitments/protocols such as the Long-range Transboundary Air Pollution which aims to limit, reduce and prevent air pollution (including long-range transboundary air pollution).[3] It can therefore be argued that the the treatment effects cannot be solely attributed to the KP.

To separate the effects of the KP from the other emissions reductions commitments/protocols the EU has in place, I removed the EU countries from the treated group. The average treatment effect is shown in column 3 of Table A.2. The magnitude of the effect is higher than those shown in the main section.

5.4 Alternate dependent variable

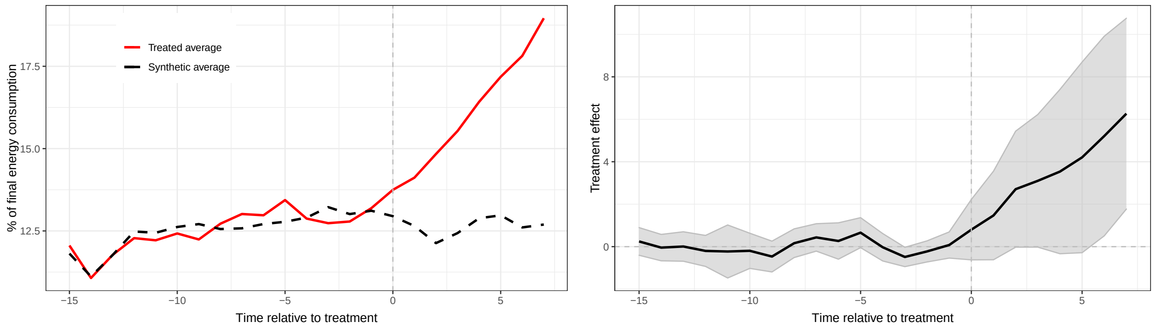
The final robustness test checks whether the result is robust to alternate definition of renewable consumption. I use renewable energy consumption per 1000 people as the alternate dependent variable. The average treatment effect is shown in column 4 of Table A.2. The result shows a positive effect of the KP on renewable energy consumption per 1000 people.

[3]https://www.eea.europa.eu/themes/air/links/institutions/the-unece-convention-on-long

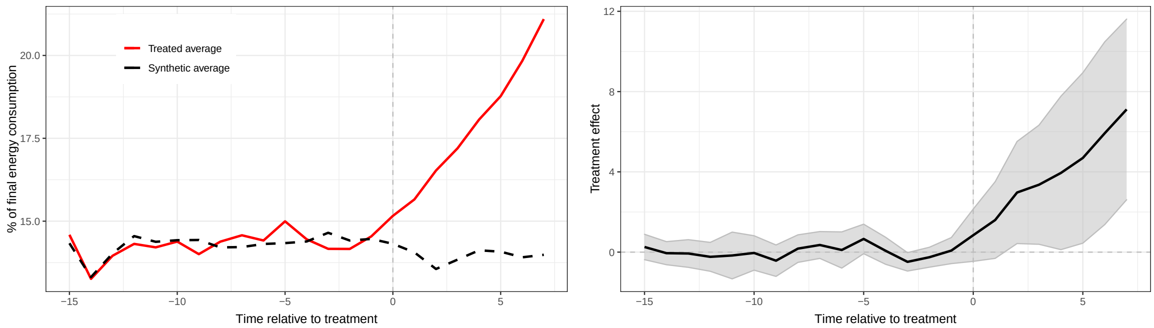
Table 2: Robustness test results

	Exclusion of CDM host countries	Exclusion of countries with limited commitment	Exclusion of EU countries	Alternate dependent variable
Kyoto	3.388***	3.771***	4.696***	0.067***
	(1.058)	(1.093)	(1.106)	(0.021)
Control variables	✓	✓	✓	✓
Number of treated countries	25	20	18	25
Number of control countries	80	88	88	88
MSPE	1.2	1.1	1.3	1.3
Unobserved factors	2	2	2	2

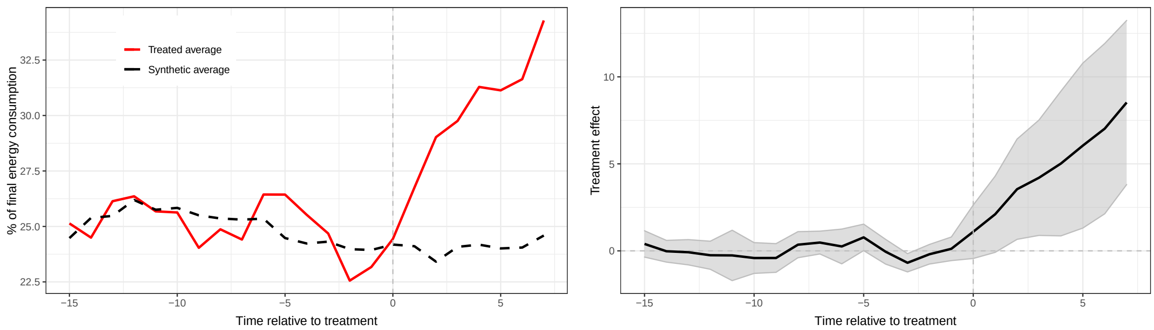
*Notes: The table presents the impact of KP on renewable energy consumption. Control variables include, real GDP per capita, the square of real GDP per capita, population growth and urban population (% of total population. Robust standard errors clustered at the country level are in parentheses. ***, **,* denotes 1%, 5% and 10% level of significance respectively.*



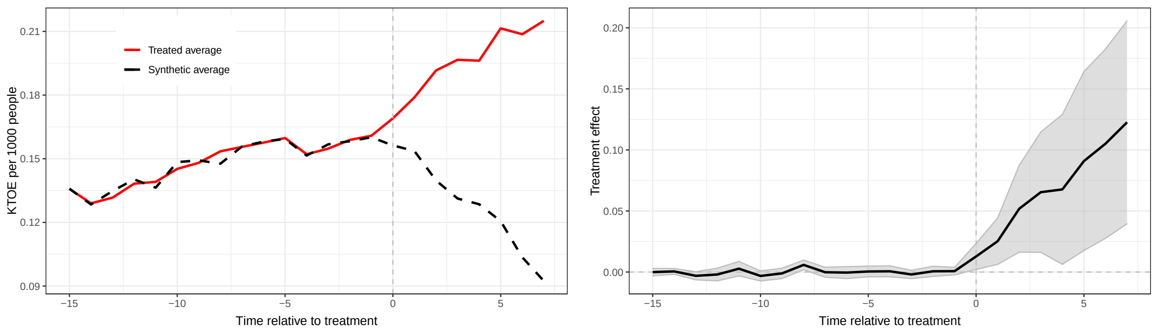
(a) Exclusion of CDM host countries



(b) Exclusion of Russia, Ukraine, Romania, Bulgaria, Poland and Czech Republic



(c) Exclusion of EU countries



(d) Alternate dependent variable

Figure 3: Robustness tests results

Notes: The figure shows the results of the impact of the Kyoto protocol on renewable energy consumption using the generalized synthetic control method proposed by Xu (2017). Panel (a) shows the average renewable energy consumption (% of final energy consumption) for the treated countries and their synthetic controls. Panel (b) shows the average treatment effect on the treated (ATT). The shaded gray area indicates the 95% confidence intervals.

6 Conclusion

The increased consumption of renewable is vital for reducing green house gas emissions thus can play an important role in limiting global temperature rise to less than 2°C. However our understanding of the impact of climate policies on renewable energy consumption is limited. In this paper, I examine the impact of the KP on renewable energy consumption. I found that the KP led to a cumulative increase in RE consumption (% of FEC) by about 16 percentage points, 6 years after its enactment. I also found that the likely mechanisms of this finding are increase in renewable energy RD&D budgets and capacity.

The policy implications of the paper are two fold. First, the results demonstrate the importance of international climate change policies to increasing the consumption of renewable energy . Renewable energy consumption is at the heart of recent international environmental agreements that have been enacted to deal with climate change. For example 182 parties to Paris Agreement had included renewable energy components in their NDCs as 15 November 2021 (IRENA, 2022). Second, concerted efforts towards research and development of renewable technologies and investment in renewable energy capacity will be required to increase the consumption of renewable energy in these countries.

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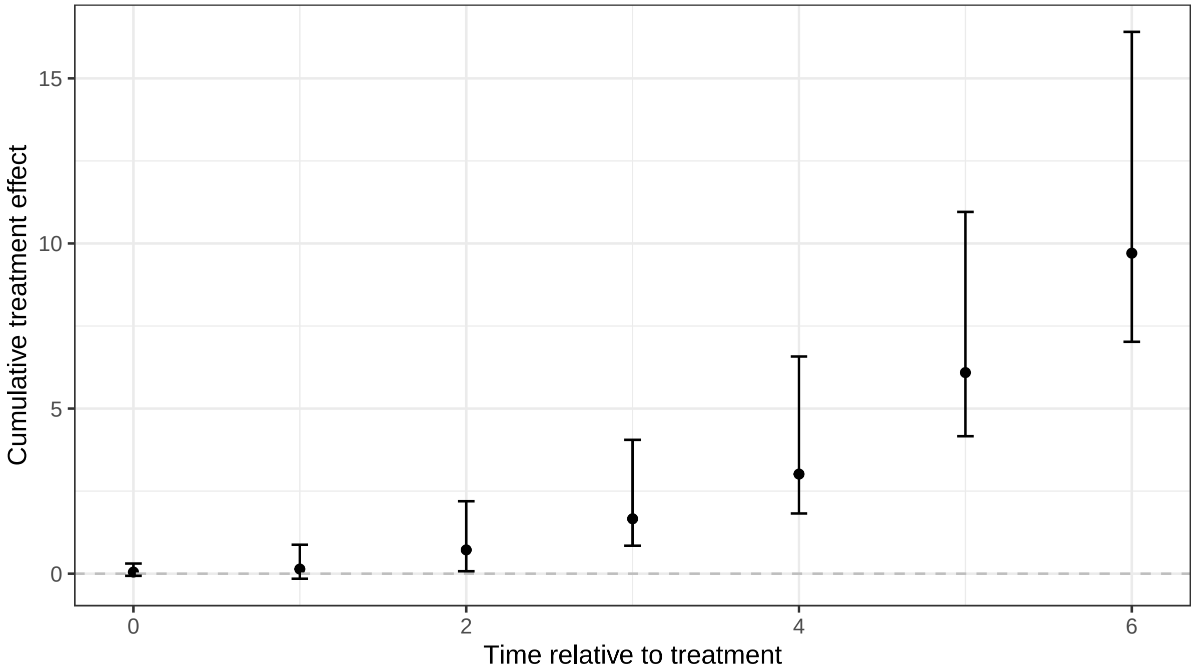
Appendix A: Additional Tables and Figures

Table A.1: Variables definition and source

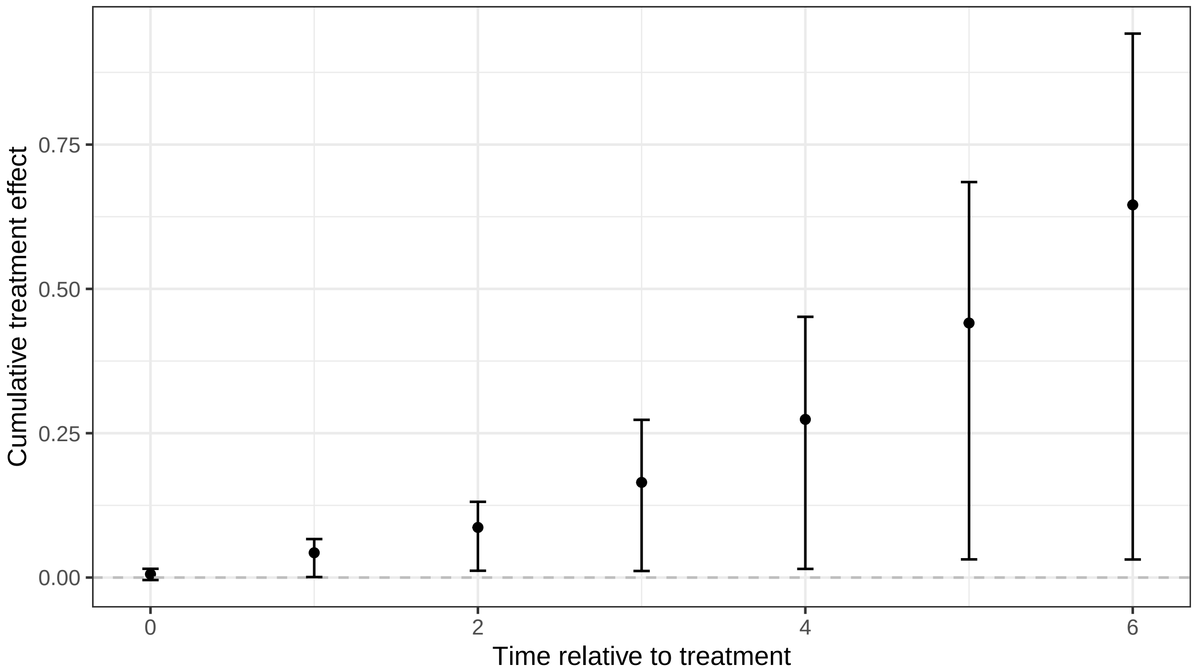
Variable	Definition	Source
Kyoto	A dummy variable that indicates whether a country enacted the Kyoto Protocol at time t	
Renewable Energy		
Renewable energy consumption	The share of renewable energy in total final energy consumption	World Bank (2022)
Renewable energy consumption per 1000 people	Total final renewable energy consumption (KTOE per 1000 people)	IEA (2022b) and World Bank (2022)
Other variables		
Real GDP per capita	GDP per capita divided by midyear population in constant local currency unit	(World Bank, 2022)
Population growth	Annual population growth rate	World Bank (2022)
Urban population	The share of people living in urban areas (% of total population)	World Bank (2022)
Renewable energy RD&D expenditure	Public energy Research, Development and Demonstration expenditures (in 2020 prices per capita)	IEA (2022a) and World Bank (2022)
Net installed renewable energy capacity	Net maximum capacity in Megawatt electric (MWe) per 1000 people	IEA (2022b) and World Bank (2022)

Table A.2: Summary Statistics

Statistic	Mean	SD	Min	Max
Kyoto	0.1	0.3	0	1
Renewable energy consumption (% of FEC)	30.3	29.0	0	97.7
Renewable energy consumption per 1000 people	0.2	0.2	0	2.5
Real GDP per capita	9.3	1.1	6.1	11.7
Population growth	1.4	1.6	−3.8	17.5
Urban population	60.1	21.0	8.9	100
Renewable energy RD&D expenditure(USD per capita)	1.7	2.7	0	18.5
Net installed renewable energy capacity per 1000 people (logs)	0.5	0.5	0	2.2



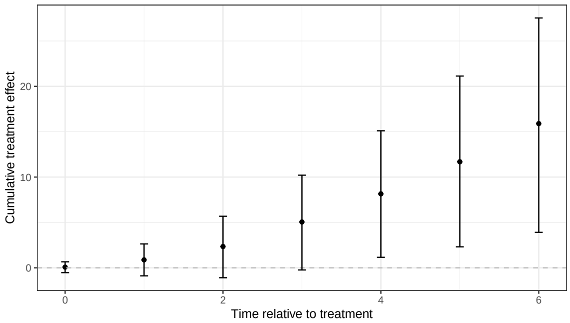
(a) Impact of Kyoto Protocol on renewable energy research and development



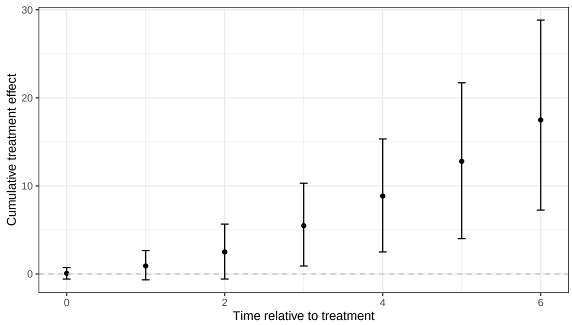
(b) Impact of Kyoto Protocol on investment in renewable energy capacity

Figure A.1: Mechanisms result:cumulative treatment effects

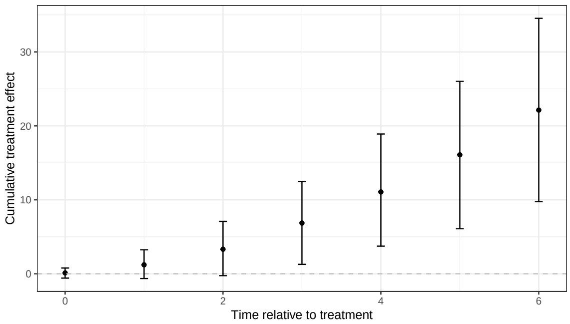
Notes: The figure shows the results of the impact of the Kyoto protocol on renewable energy research and development using the generalized synthetic control method proposed by Xu (2017). The shaded gray area indicates the 95% confidence intervals.



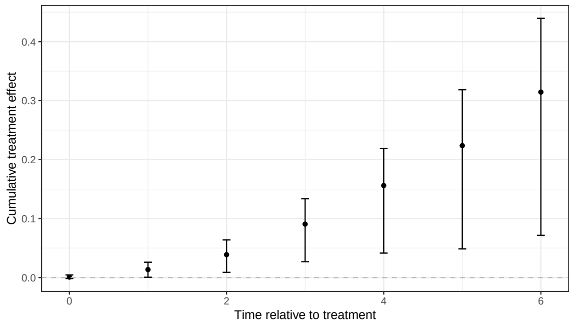
(a) Exclusion of CDM host countries



(b) Exclusion of Russia, Ukraine, Romania, Bulgaria, Poland and Czech Republic



(c) Exclusion of EU countries



(d) Alternate dependent variable

Figure A.2: Robustness tests results: Cumulative treatment effects

Notes: The figure shows the results of the impact of the Kyoto protocol on renewable energy consumption using the generalized synthetic control method proposed by Xu (2017). The shaded gray area indicates the 95% confidence intervals.