Is climate policy reform compatible with economic emergence?

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Abstract

In 2012, the Gabonese government adopted a climate strategy to reduce carbon dioxide emissions, move away from the historical reliance on oil production and emphasize sustainable development. We use panel data (1999-2018) and the synthetic control method to estimate the policy impact. We estimate that annual per capita emissions feel by at least 24.16% translating to an aggregate 10-11.7 million metric tons since enactment. We do not find evidence of significant loss in national output. Key policy drivers include 1) reduction of emissions from oil and petroleum refinement processes 2) sustainable land use planning in agriculture, forestry and mining 3) growing domestic utilization of renewable energy. The study contributes to the literature on environmental governance, policy discourse, and climate, with implications for sub-Saharan African countries. It also provides, in part, key insights to policymakers focused on the mitigation and adaptation of climate change in emerging and developing economies.

Keywords: Climate change, Congo basin, Sustainable development, Synthetic control method.

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1 Introduction

Anthropogenic emissions from energy demands are greatly contributing to global warming, intensifying and increasing the frequency of storms, droughts, wildfires and other extreme weather events (Knutson and Tuleya (1999), Sarkar (2012), Diffenbaugh et al. (2015), Ranson and Stavins (2016), Habibullah et al. (2022), Powell (2015), Yuan et al. (2022)). While climate change represents a global and growing threat, fitting and successful policies have become increasingly difficult to formulate given the important regional and economic disparities.

For example, energy demand is projected to increase everywhere, but more so outside industrialized economies (Wolfram et al., 2012). Within the next decades, green house gases emissions associated with population growth will intensify, particularly in the developing world (DeLong et al., 2010). This creates serious concern, as emerging countries accelerate natural resources extraction with the associated pollution stemming from economic transformation (Markham, 2019). In this context, we witness a pivotal stage in global climate history. If energy generation from fossil fuels persists and expands, there is a genuine risk of 'hothouse earth' scenario with irreversible environmental damages due to a rapid biome shift (Steffen et al., 2018).

The situation has led global leaders to take several steps toward mitigating and possibly reversing the current trends (Holzinger et al., 2011). The Kyoto Protocol (1997) and Paris Agreement (2015) are examples of such commitments. In addition, the United Nations Framework Convention on Climate Change (UNFCC) has called for the immediate conception and implementation of policies specifically oriented towards climate change mitigation and adaptation (Somorin et al., 2012). Nevertheless, besides the nominal engagement, environmental policies have encountered greatly varying level of success across regions. For example, several OECD (Organization for Economic Cooperation and Development) countries have taken practical measures to curb emissions and diversify energy production, while emerging and developing countries have achieved a more mitigated success (Parris (1999), Bell and Russell (2002), Holzinger et al. (2011), Somorin et al. (2012)).

Yet, the current status cannot be adequately analyzed without accounting for the pressing economic challenges of non-industrialized economies targeting rapid growth while attempting to simultaneously reduce carbon dioxide emissions (Walter and Ugelow, 1979). Consider the example of sub-Saharan African countries. Climate strategy progresses are less rigorously documented in the region due to data availability and pervasive context mismatches. Researchers have found that environmental policies funded by international agencies often ignore localized challenges in non-industrialized countries, such as substandard national infrastructures and difficulties in adopting market-based policies that have been successful in Europe or the United States (Bell and Russell, 2002). Such challenges may only be remediated by a better localized understanding and assessment of environmental policy reforms (Owen et al., 2013).

Gabon offers a relevant case study for several reasons. First, Gabon is an emerging economy with relatively high levels of CO_2 emissions due to oil production. Second, the majority of the territory (88%, Mongabay) is covered with equatorial rain forests and Gabon hosts the sixth-largest oil reserve in sub-Saharan Africa (US Energy Information Administration (EIA)). Third, its National Climate Plan of 2012 is outstanding in the sub-Saharan region with respect to its rigorous emissions' targets, and accountability systems. Surprisingly, to date, very little empirical evidence has explored whether the anticipated causal impacts materialized or even attempted to estimate their magnitude. Gabon's reform may be a remarkable case study with several lessons such as monitoring practices, private sector negotiations, reduction of emissions in the petroleum refinement process, protection of rain forests and management of land use may benefit policymakers, but the evidence is currently limited.

This study employs the synthetic control method (Abadie, 2021) to estimate the CO_2 reductions caused by the National Climate Plan of Gabon. We use panel data on a group of sub-Saharan and middling income countries between 1999-2018. Our results show that between 2013 and 2018, Gabonese per capita emissions fell by at least 24.16% or 10.41 million of metric tons in CO_2 emissions at the national level over the six years.[1] Given that sustainable economic growth is critical when considering successful environmental policy intervention and implementation among developing countries we also analyze the impact on output. We do not find evidence of a significant loss in per capita income compared to other sub-Saharan African countries.

The rest of this article is organized in seven sections. Section 2 presents Gabon's backdrop and National Climate Plan. Section 3 explores Gabon's environmental culture and impact on various sectors. Section 4 presents the data used in the empirical estimation. Section 5 presents the empirical analysis and our results. Section 6 presents some sensitivity analysis of our findings. Section 7 investigates the impact on output, and we conclude in Section 8 and policy implications are discussed.

[1] To put this policy impact into perspective, the total reduction over the six years is equivalent to the cumulative 2019 carbon dioxide emissions of Chad (2.25), Central African Republic (0.2), Mali (5.8) and Niger (2.1) combined. The influence of the National Climate Plan has been such that in 2019 Gabon became the first country in Africa to receive payments to reward carbon dioxide emissions (United Nations.)

2 Backdrop and the Gabonese National Climate Plan

Gabon is a small central African country lying in the Congo Basin. The country has a dense equatorial forest that is home to several hundred endemic species (Walters et al., 2016). It gained independence from France in 1960 and has a population of 2.27 million (World Bank, 2021). In terms of living standards, the country ranked fourth in 2022 among African countries with a nominal GDP per capita of $17,848 but has a relatively high level of inequality.[2] In 1931, several oil deposits were found in the region of Libreville, and Gabon has been a major oil producer ever since. The country is also a member of the Organization of the Petroleum Exporting Countries (OPEC).

The economy revolves around four main sectors.[3] Petroleum and natural gas are dominant. The petroleum sector represents over 40% of the national product and brings in about 60% of public revenues (PNCG, p. 60). According to the Gabonese government, oil production has grown by 5% between 2009 and 2010. Comparatively, natural gas is a smaller player in the energy sector (PNCG, p. 55). Next, there is the wood industry. In 2012, more than 80% of the Gabon surface was covered with forest. Since its independence, the country had been a leading exporter of wood. In 2012, the new forestry code required the creation of "exploitation forests" by commercial companies to curb environmental damages. Gabon is also an important worldwide producer of manganese and has large unused reserves. Last and least, the agricultural sector is small, as Gabon imports about 80% of its food. Most of the agriculture is at the subsistence level. The sector has continuously decreased as a share of the national gross product. It represented 15% of GDP in 1960, but only about 1% in the 2010s (PNCG, p. 41). As expected, the sector accounts for only about 2.5% of national GHC emissions.

Several climate observations prompted the creation of the National Climate Plan (*Plan National Climat*). According to the United Nations (UN), since the 1960s, local Gabonese temperatures had increased by 0.6 Celsius ($°C$) or an average 0.14 $°C$ per decade. Without intervention, local projections set temperatures to rise between 0.9 and 2.5$°C$ by 2060. Rains had also decreased by 2.6% per decade. Gabon is an important country within the central African region. Edjang (2021) reports that rainforests in the Congo Basin are the second largest worldwide and consume close to 1.5 billion tons of CO_2 annually (4% of global emissions). The United Nations reports that the region as a whole had suffered

[2] Nonetheless, in 2017, World Bank estimates found that about 33.4% of the population lived under the poverty threshold ($1.90 dollars a day) compared with 38.3% among sub-Saharan African countries as a whole.

[3] Information about the economic features and policy change in Gabon are also available in the original document released on the government's website (Plan National Climat Gabon (PNCG)).

the loss of over 6 million hectares of humid primary forest since 2001 (UN).

The enactment of the policy began by creating the "*Conseil National du Climat (National Climate Council).*" The policy was designed to go beyond the climate aspect. The National Climate Plan was an environmental policy enacted within the larger vision of Gabon to establish itself as an emergent economy. For this reason, the changes went further than limiting carbon emissions per se, but recommended new ways to expand economic activity sustainably via intermediate annual goals, accountability and practical development strategies.[4]

Prior to the policy, several feasibility studies were carried out to further understand the legal requirements of such a large-scale operation with respect to the various needs and constraints of the local companies and foreign investors. These government-conducted studies aimed at forecasting the impact of the policy on different sectors of the economy and on the country as a whole. Beyond the public financial backing of the policy, the French government also provided support for this plan (528 millions FCFA ≈ $817,000). A priority of the "*Emergent Gabon*" plan was sustainable development, and this would influence the creation of the country's National Climate Plan in 2012. The National Climate Plan works alongside negotiations made with the United Nations Framework Convention on Climate Change (UNFCCC) and Gabon's own National Observation System of Natural Resources and Forests (SNORNF) to monitor and evaluate emissions associated with agriculture, forestry and other land use sectors (Conseil National du Climat). SNORNF uses satellite imaging, field inventories and modeling to effectively monitor and evaluate the National Climate Plan's progress. This approach has been essential in the Climate Plans success as it helped to corroborate the Climate Plan's operative measures in emissions reductions, land use activities and increasing carbon sequestration (Conseil National du Climat).

To reduce emissions, Gabon has principally focused on land use planning and gas flaring. Land use planning targeted agriculture, mining, forestry and infrastructures with a distinct interest in deforestation and managing vulnerability to coastal erosion. Gas flaring reduction was key to the policy success. The objective was reducing the volume of waste products flared during oil production by 60% by 2015 (PNCG, p. 61): In the "*Seconde Communication Nationale*" of 2007 flaring had been identified as the

[4]Protected forests grew under the policies implementation but also included provisions for the creation of new off-shore and on-shore oil wells with a more environmentally conscious approach. In 2010, the Gabonese Government adopted a new national policy called Emergent Gabon, which aimed to diversify the countries' economy away from overt reliance on forestry and the oil indutry Aki et al. (2018). The Grantham Research Institute on Climate Change and the Environment (LSE) provides a copy of the original government issue discussing these points. The document was originally produced by the Gabonese government and is available only in French to our knowledge.

main driver of CO_2 emissions (59% of the bulk while transportation emissions accounted for only 8% and industrial emissions for 17%).[5] Gas flaring reform was the crucial instrument to achieve a significant reduction of GHG emissions. Within the general plan, a specific provision for the reduction of flaring and improvement of refined associated petroleum was established. Flaring was to be reduced to the minimum possible, with 2014 being the year with the greatest expected decrease. A non-acceptable flaring threshold was created for each specific field of oil extraction. Continuous flaring was forbidden except with particular permissions or for emergency. In addition to these provisions, the Gabonese government adopted reinjection procedures of gas back into oil wells to avoid any flaring at all.[6] Lastly, domestic renewable energy consumption was encouraged, with a specific focus on hydroelectric energy generation.

3 Environmental, social, and economic policy impacts

While December 2012 marked the official start of the policy enactment, Gabon had put an emphasis on sustainability since the early 90s. Several forest management strategies since that period spelled out the countries' commitment to maintaining biodiversity and limit pollution (PNCG, p. 36). Since 2002, 13 national parks (7.41 million acres) have been created. In addition, 1.3 million hectares of exploitable forest became illegal to exploit to protect large virgin forests in the country.

In 2001, the Government of Gabon (GoG) signed into law a Forest Code. The Forest Code ensures sustainable forestry management practices, where harvest rotations are required to be at least 20 years. The Forest Code was also used to help create a more sustainable economy, where 75% of raw timber was required to be harvested and processed domestically. By 2009 the country was not meeting their domestic processing targets, so President Ali Bongo Ondimba halted all log exports and required timber processing to be 100% domestic. This unorthodox policy did not come into effect until 2011, and ultimately resulted in emissions reductions as total wood production dropped.[7] Friedlander et al. (2014) study the marine biodiversity of Gabon in recent years in light of the country's new environmental

[5]In the early 2010s about 95% of greenhouse gases (GHG) were carbon dioxide (CO_2) followed by methane (CH_4, 4%) and a negligible share of nitrous oxide (N_2O).We later conduct similar analyses of the evolution of these two GHG and find that the National Plan did not affect them significantly. The results are available upon request.

[6]Flaring aims at burning the natural gas associated with oil extraction. It is deemed extremely wasteful. The technique dates back to the beginning of the refinement process over 160 years ago. An alternative that is more costly is to re-inject the natural gas back in original wells. This, however, is not the norm.

[7]Gabon CO_2 monitoring of forests was based on a large national system of measurement (115 sites) located in rains forests throughout the country. Based on measurements and comparison with neighboring countries, the Gabon government estimated that 78% of the sites had significantly increased their rate of CO_2 trapping (PNCG, p37)

efforts. They find that Gabon is now a world leader in conservation, with new oil explorations and biodiversity conservation that have been increasingly integrated into Gabon's operations.

More recently, one of the major impacts of the policy has been the recognition of Gabon's achievements by the UN Central African Forest Initiative's (CAFI) in 2019. Gabon received the first installment of a \$150 million payment over 10 years, making it the first African country to receive payment for CO_2 reductions (UN). Professor Lee White who serves as the country's Minister of Water and Forests said: "*This first payment of ODA (Official Development Assistance) financing, which is proportional to our historic emissions reductions in 2016 and 2017 at \$5/ton, will finance projects that preserve Gabon's forests. It also paves the way for Gabon to finalize the systems that will be required to enable the country to formally sell carbon credits in the future* (UN)."

In summary, the National Climate Plan was part of a larger vision of economic emergence. Gabon had been an environmentally engaged country, but the policy confirmed its orientation toward sustainable growth. Flaring regulations were the critical change, especially considering that Gabon is an oil exporting country. Forestry regulations, including log exports bans and the replanting of trees, have also played an important role. Gabon's Climate Policy is critical for the country's emerging economy as well as the residents well-being. On this front, evidence has suggested that climate change mitigation improves agricultural outcomes, and in doing so, reduces local displacement and international migration (Falco et al., 2019). The unintended benefits brought about by Gabon's Climate Plan may help solve long withstanding issues of income disparities. Environmental initiatives may lead to employment generation, improved nutrition, greater access to electricity and improved ecosystem services and other social benefits (Simon, 2013). This prompts the question: Is there empirical evidence to support the effects of this policy, and if so, how is this measured?

4 Data

To address this question, we use annual panel data spanning 1999 to 2018 for 95 countries.[8] Our measure of carbon dioxide emissions (CO_2) comes from the World Bank's World Development Indicators (WDI). This is our measure of interest.[9] We express emissions in per capita terms.

[8] We use country rankings of Blankenau et al. (2007) and exclude high income countries for comparability, but keep oil producing ones nonetheless. The majority of the sample includes middle and lower income countries. In alternative comparison pools, we focus on sub-Saharan Africa.

[9] Although carbon dioxide emissions are naturally produced by photosynthesis, it is also a product of fossil fuels combustion, wood burning, waste materials and other industrial activities such as cement production. It is classified as

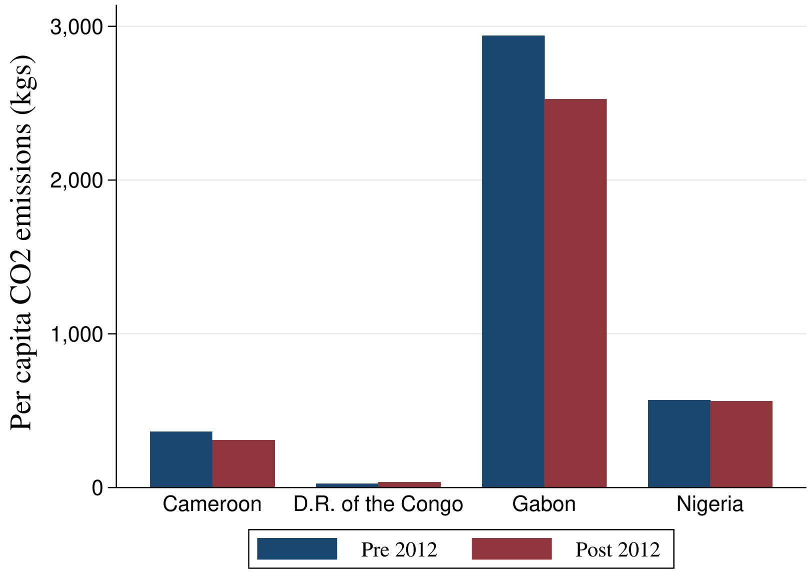

Figure 1: CO_2 emissions (kilograms per capita) in the Congo Basin. Prior to 2012, Gabonese per capita CO2 emissions averaged 2937.9 kgs/person but is lowered to 2444.1 kgs/person. A difference of about 493 kgs/person annually. Several border countries saw their CO_2 emissions mostly stagnate at the same time.

Figure 1 compares Gabon to three neighboring economies. Two elements are striking. First, Gabon produces significantly more CO_2 per person compared to neighboring countries. This comes as no surprise, given the large production of fossil fuel since 1970s. Second, while some surrounding countries have experienced slight emissions decreases, the trend has overall been one of stagnation. Gabon's emissions, in contrast, have visibly decreased since 2012. This is the more noteworthy when put in perspective with Gabon's sustained economic growth (Ampofo et al., 2022).

In addition, we gather data on government spending and the percentage of the population leaving in urban areas. The first accounts for the size of government and its activity, while the second is an index of the transition from rural toward urban economy. In 2021, Gabon had a staggering 90% of its population living in urban areas, compared to only 42% for the rest of sub-Saharan Africa (WDI). Urbanization has also been linked to significant carbon dioxide increases (Marcotullio et al. (2012), Crippa et al. (2021), Chen (2022)). Chen (2022) also document a significant relationship between government size and CO_2 emissions. The two series also come from the WDI database.

The second database used is the Penn World Table 10 (PWT10, Feenstra et al. (2015)). We obtain

a green house gas with global warming potential of 1 representing the largest share of greenhouse gases (Olivier et al., 2017).

real Gross Domestic Product (GDP, Purchasing Power Parity (PPP) $2017) divided by the total population. This is a measure of economic activity and standards of living (Hamilton, 2021). Another important determinant of productive capacity is the per capita level of physical capital available and its annual depreciation level.[10] Both series are also included. We also add a measure of human capital. Yao et al. (2020) investigate the link between CO_2 emissions and human capital among OECD countries and find that educational achievements positively contribute to lower emissions. The second motivation to incorporate human capital level is the finding of Bell and Russell (2002) that national capabilities is an important determinant of climate policy success.[11]

Compared to other sub-saharan African economies, Gabon has several important features that guided our choice of initial comparison pool. It is classified as an upper-middle-income country by the World Bank (2021) with a developed oil sector. Gabon is therefore comparable to other oil exporting countries and several middle income countries worldwide. Geographically, however, Gabon is a sub-Saharan African country that shares several historic commonalities to others in the region. Our initial comparison pool seeks to make a compromise by including sub-Saharan African countries as well as middle income economies outside the region. From the initial sample, we exclude high income countries, however, except OPEC members.

5 Empirical methodology

5.1 The synthetic control method (SCM)

Difference-in-differences (DiD) methods have been extensively used in comparative studies to estimate the influence of policy shifts. The approach relies on the parallel trend assumption to compare treated and control units. In essence, the econometric procedure consists in producing two groups with comparable evolution prior to the policy shock. Based on this assumption, deviations from the comparison units are attributed to the policy and measured as a causal effect. Numerous environmental studies have used this approach to estimate the impact of policy shifts (Ott and Weber (2018), Ferentinos et al. (2021), Gu et al. (2022), Mertens (2022)). One recurring criticism of this method has been

[10]Physical capital is measured as the market value of all buildings, machines, computers, pieces of software and other non-human factors of productions available to an economy in a particular year. Depreciation rates are based on changes in the annual value of these assets (Feenstra et al., 2015).

[11]The measure of human capital is based on educational achievement measured from Barro and Lee (2013) and Mincerian returns to education (Mincer, 1974).

the difficulty to formally test either the parallel trend assumption or the choice of the control units, which has been deemed arbitrary at times. When one unit is subject to a policy shift while others are not, Abadie et al. (2010) note that this may lead to identification problems if the control units have diverging time trend compared to the treated unit.[12] In contrast, the synthetic control method (SCM) waives the parallel trend assumption and relies instead on an algorithm to choose and weight the comparison units out of a donor pool of potential control units. This section briefly presents this algorithm and its methodology.[13]

Under the National Climate Plan, we observe $J + 1$ countries, and only Gabon is exposed to the reform. Based on the matching literature, we refer to all potential controls (Botswana, Cameroon, ..., Nigeria) as the "donor pool." In our paper, the initial donor pool is made up of 95 countries.[14] We also assume that Gabon is uninterruptedly affected by the reform after the 2011.[15] Let Y_{it}^N be the annual per capita CO_2 emission in country i at time t in the absence of any intervention with $i = 1, ..., J+1$, and time periods $t = 1, ..., T$. Let T_0 be the number of pre-reform years (12 years in our case - from 1990 to 2011), with $1 \leq T_0 < T$. Let Y_{it}^I be the outcome that would occur at time t, assuming that country i is exposed to the intervention in period $T_0 + 1$ to T.

We also assume no interference between countries (Rosenbaum, 2007). Let now $\alpha_{it} = Y_{it}^I - Y_{it}^N$ be the effect of the Gabon reform for country i at time t, and let D_{it} be a binary indicator based on exposition. In other words, D_{it} is one if the country is Gabon after 2011 and zero otherwise. It is the only country exposed to the National Climate Plan, and only after 2011. We obtain:

$$D_{it} = \begin{cases} 1 & \text{if } i = 1 \text{ and } t > 2011 \\ 0 & \text{otherwise.} \end{cases}$$

The observed outcome for the country i at time t is therefore:

[12] Another point of contention, is the scale dependence of the identification assumptions in DiD (Mertens, 2022). The measurement and transformation of the outcome variable is relevant for the identifications assumptions adequacy. Lechner et al. (2011) emphasizes that this is not a feature shared by other non-parametric identification strategies like instrumental variables or matching, making the DiD approach a semi parametric identification strategy.

[13] For a more detailed exposition of the SCM, see Abadie et al. (2010, 2015).

[14] At the sensitivity analysis stage, we experiment with different donor pools as well, focusing on sub-Saharan Africa and other groups.

[15] Abadie et al. (2010) note that in practice, the impact of a policy change could be felt earlier than the formal enforcement date. In such cases, they advise reconsidering T_0 (policy beginning) to be the first period in which the outcome can possibly be affected. We experiment with setting the treatment period in 2010 and 2012, but the results are largely similar. Given the enforcement of several measures before 2012, we use 2011 as the candidate date.

$$Y_{it}^I = Y_{it}^N + \alpha_{it} D_{it}. \tag{1}$$

We target the estimation of $(\alpha_{1,2013}, ..., \alpha_{1,2018})$,

$$\alpha_{1t} = Y_{1t}^I - Y_{1t}^N = Y_{1t} - Y_{1t}^N.$$

Each country besides Gabon is assigned a non-negative (but possibly null) weight w_i such that all weights sum up to one. We thus have a $(J+1)$ vector of weights $W = (w_2, ..., w_{J+1})$. The weights defining a given synthetic control W^* are chosen to minimize the sum of squares:

$$\|X_1 - X_0 W\|_V = \sqrt{(X_1 - X_0 W)' V (X_1 - X_0 W)}, \tag{2}$$

where X_1 is a vector of predictor variables for Gabon, X_0 is a matrix of the same predictor variables for each donor pool country, and V is a symmetric, positive, semi-definite matrix of weights assigned to the predictor variables. Abadie and Gardeazabal (2003) select predictor variables weights such that the outcome variable path for the treated unit in the pre-intervention period is best reproduced by the resulting synthetic control. Equation 2 aims to minimize the Euclidian distance between control and treatment units (Abadie, 2021).

Once the weights vector W^* is obtained, we combine it with a matrix Y_0 of each donor country outcome value. We thus create the counterfactual outcome path $Y_1^* = Y_0 W^*$. The estimated annual post reform impact is given by the difference between the observed and the counterfactual value for Gabon. The estimated dynamic treatment effect is thus:

$$\widehat{\alpha_{1t}} = Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt}, \tag{3}$$

where $j = 1$ is Gabon and $j \in \{2, ..., J+1\}$ are the donor pool countries, and w_j^* are weights assigned to each country in the donor pool. The average treatment effect (ATE) is given by:

$$ATE = \frac{1}{T - T_0} \sum_{t=T_0+1}^{T} \widehat{\alpha_{1t}}. \tag{4}$$

The outcomes in both the treated and the donor pool countries are assumed to follow a linear factor model:

$$Y_{jt}^{0} = \delta_t + \theta_t Z_j + \lambda_t \mu_j + \epsilon_{jt} \tag{5}$$

where Y_{jt}^{0} is the outcome without intervention, δ_t are common time effects, θ_t is a vector of parameters, Z_j are observed covariates not affected by the reform, λ_t are unobserved common factor shocks, μ_j are unknown factor loadings, and ϵ_{jt} are unobserved, mean zero, country level transitory shocks. When $\lambda_t = 1$ and $\mu_j = \delta_j$, the model is simplified to a two-way fixed effects model.

The SCM method has gained in popularity in recent years for several reasons (Abadie, 2021). The control unit selection process is less arbitrary than comparable methods due to the data driven approach. We later show the weights for each country involved. In addition, the method allows many robustness checks because it is possible to vary the donor pool. It is also an advantage that the results can be reported visually, showing the disparity between actual Gabon and its synthetic control overtime. This makes the result more intuitive. Of these advantages, the last one can also represents a challenge. In practice, the SCM does not provide an R^2 or standard errors for the estimate or other comparable statistics to rule for or against significance. Instead, the initial authors employ placebo procedures to compare the treated unit to the other countries. [16]

5.2 Results

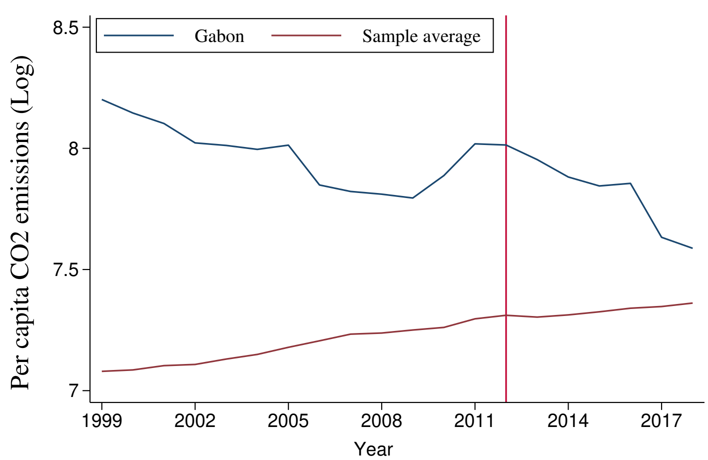

Figure 2: Trends in CO_2 emissions (Log). Gabon versus sample average of 95 countries. Gabon's emissions are larger than the sample average, but are declining. In comparison, the sample average per capita emissions steadily increased since 1999.

[16] The method provide a "*p-value*", which is the probability that the estimated effect is the result of chance. We compare this quantity against common significance levels in comparative studies to assess significance.

Figure 2 shows the trend in per capita CO_2 emissions in Gabon compared to the sample average. Gabon is visibly a large emitter of carbon dioxide, but is also on a different trend compared to other countries. More precisely, between 1999 and 2018, the average country emissions grew by around 28.1% while Gabon's emissions have decreased by about 61.4%. This suggests that, a priori, the rest of the sample may not be a good comparison for Gabon due to this divergence. In other words, the classic parallel trend assumption may not be fitting. Due to this issue, a DiD estimate may be biased.

Table 1: Per capita CO_2 predictors means before Gabon's climate reform

Variables	Gabon	Synthetic Gabon	Average of 95 countries
Ln(GDP per capita)	9.52	9.77	8.96
Government spending (%GDP)	13.79	10.91	14.61
Ln(Capital per capita)	11.07	11.18	10.29
Depreciation (%)	4.82	4.37	4.46
Urban population (%)	82.31	75.34	54.43
Human capital	2.29	2.50	2.30
Ln(CO_2 per capita 2000)	8.14	8.14	7.08
Ln(CO_2 per capita 2003)	8.01	7.97	7.13
Ln(CO_2 per capita 2006)	7.84	7.88	7.20
Ln(CO_2 per capita 2009)	7.79	7.81	7.25
Ln(CO_2 per capita 2010)	8.01	8.00	7.29

Notes: All variables except lagged emissions per capita are averaged for the period 1999-2011. Per capita income is an indicator of economic activity (purchasing power parity (PPP) adjusted and measured in 2017 U.S. dollars.). Government spending is a measure of government size expressed as a percentage of national output. Capital per capital is a measure of access to non-human factors of production. Depreciation is the rate of value loss of these assets. Urban population is the percentage of the population living in cities. Human capital is another indicator of productive capacity.

After the policy change, the per capita emissions of Gabon continued to decrease. Our objective is to estimate the causal effect of this policy change by quantifying what may have occurred without it. The synthetic control method allows to construct that counterfactual outcome. Table 1 shows the comparison between Gabon and its synthetic counterfactual, as well as the sample average. This synthetic Gabon is created based on the convex combination of countries in the donor pool that most closely follow Gabon, by following the minimization procedure of Equation 2. The identification assumption is that this comparison unit represents the path of Gabon without the National Climate Plan.

Table 1 compares the values of the key predictors across Gabon, the synthetic control and the donor pool before treatment. For the majority of the predictors except the level of government spending and the urban population, Gabon and its synthetic counterpart are similar. The largest discrepancy exists in urban population. This is to be expected, since the SCM allocated a negligible weight to this predictor of CO_2 emissions. The predictors are weighted with an emphasis on lagged values of emissions which are near identical between treated and control units.[17]

Table 2: Country weights in synthetic Gabon

Country	Weight	Country	Weight	Country	Weight
Singapore	0.61	Zimbabwe	.296	Nepal	0.063
Togo	0.02	Rwanda	0.002		

Notes: Since no extrapolation occurs in the SCM method, all weights are between 0 and 1 and $\sum w_j = 1$.

In addition, Table 2 presents the weights assigned to the combination of countries that make up Gabon's counterfactual or synthetic control. The rest of the countries in the donor pool have a weight of zero. Gabonese CO_2 emissions are most similar to a combination of Singapore, Zimbabwe, Nepal, Togo and Rwanda. The large weight allocated to Singapore (0.61) is reasonable for several reasons. The data shows that the trends in CO_2 emission had followed nearly identical path up until 2012 (WDI). In addition, both countries have a relatively large size of government compared to their GDP. In 2000, Gabon's government expenditures averaged 9.6% compared to 10.5% for Singapore. Public expenditures have been shown to be an important determinant of emissions (Cheng et al. (2022)).

[17] This is the V matrix chosen among all positive definite and diagonal matrices to minimize the mean squared prediction error of national CO_2 emissions (Abadie et al. (2010), Andersson (2019)). In particular, per capita emissions in 2000 (.271), 2003 (0.197), 2006 (0.284), 2009 (0.095), 2011 (0.151) while the weights assigned to other predictors are small (about 4%). We experimented with different combinations of lagged CO_2, -e.g., (2000, 2004, 2008) and (1999, 2002, 2004, 2008, 2011) and more. We kept the combination that gave the closest pre-period fit. In each case, the results do not change significantly compared to the displayed combination. We also run a version including fertility and trade volume as additional predictors. The literature suggest that fertility is an important determinant of population growth, which can affect emissions (MacKellar et al., 1995). Trade volume (%GDP) as well is an important indicator of economic activity (Busse and Königer, 2012). These additions do not change our results, as their cumulative weight is less than 0.00001. All these results are available upon request from the authors.

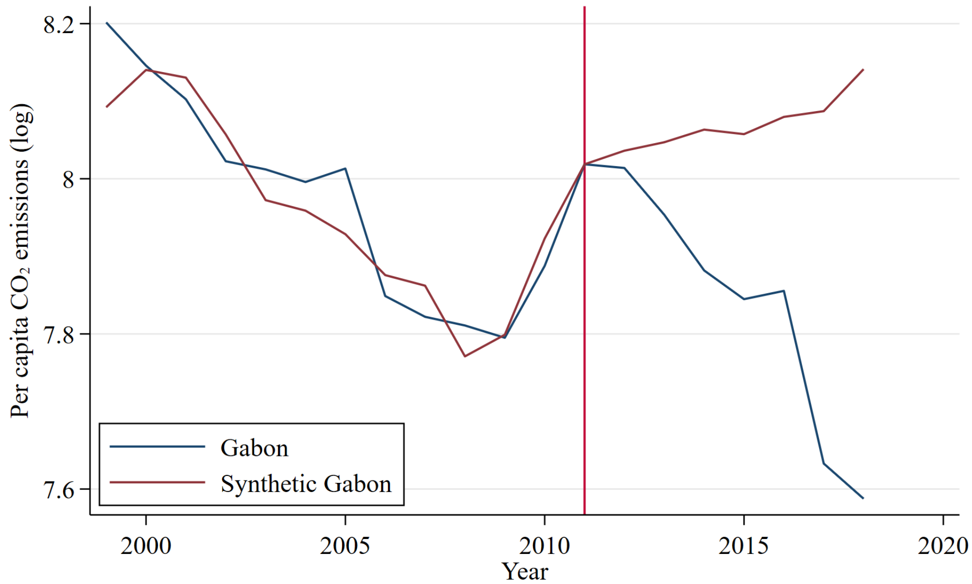

Figure 3: Trends in CO_2 emissions of Gabon versus synthetic Gabon (1999-2018). Before the policy shift, Gabon and its synthetic control trend are close but diverge significantly afterwards.

Figure 3 shows the trajectory of Gabon, and it's synthetic control. Prior to 2011, the two trends are similar, following each other closely. This is one of the advantages of the SCM over estimators that rely on the parallel trend assumption, which is difficult to formally test. After the policy, the two lines begin to diverge noticeably. Emissions in the synthetic Gabon rises while actual emissions experience a clear decline. For each year post enactment, the estimated impact of the National Climate plan is thus the difference between the observed path and our synthetic control's.

Table 3 shows the estimated gap for each year. Over the six years following the policy, there has been an average 24.16% decrease in per capita carbon dioxide emissions or - 0.86 metric tons per person. The decrease is most pronounced after 2016 pointing to a timing dimension for this policy impact. Notably, by 2018, emissions are estimated to have been more than 55% lower compared to what they would have been without the National Climate Plan. Aggregating this over the whole population for the entire posttreatment period gives an estimated 10.41 million tons decrease of CO_2 emissions as a result of the policy. This suggests that the National Climate Plan substantially lowered carbon emissions in Gabon.

Table 3: The estimated impact of the 2012 Gabon National Climate Plan

Year	2013	2014	2015	2016	2017	2018	Average
Percentage point difference (%)	-9.35	-18.16	-21.27	-22.42	-45.43	-55.37	-24.16
Per capita effect (metric tons)	-0.30	-0.58	-0.66	-0.71	-1.31	-1.61	-0.86
National effect (million of metric tons)	-0.56	-1.09	-1.30	1.43	-2.70	-3.41	1.73

Notes: All estimated effects are computed as the difference between Gabon's observed outcome and the synthetic control unit for each year following the policy intervention. National effect is calculated as the product of the per capita reduction multiplied by the population in each year. This number is then expressed in million of metric tons.

However, we need to consider an important assumption of the SCM design. That is the assumption of the absence of interference between countries. This could be violated in our context if Gabon's policy simultaneous raised regional environmental awareness "contaminating" other countries and influencing their own national activities.[18] We assess that this potential violation is unlikely for several reasons. One strength of our donor pool is that we included potential control units not only on the basis of geographical vicinity, but also economic development level and oil sector's importance. Although Gabon has historically been a large CO_2 emitter with a relatively large GDP per capita (among sub-Saharan countries), it is hardly plausible that the policy had any effect on countries located in distant regions, namely, Singapore and Nepal which make up the bulk of the synthetic control.

5.3 Inference

Next, we turn to the significance of our estimates. In this regard, the SCM differs from other estimation approach in that we do not produce a t-statistic nor an R^2 to assess the explanatory power of the model. Instead, we rely on a series of tests that put into perspective the evolution of CO_2 emissions in Gabon compared to the non-treated countries of the donor pool. These are the so-called placebo methods, which are in intuition close to their counterpart in clinical trial statistical methods, which are the origin of the term (Abadie et al., 2010).

[18] One example of this issue has been treated by Rios and Gianmoena (2018) which is a spatially augmented green Solow model that takes into consideration technological externalities and interference in a panel of 141 countries. The study shows that there is a plausible CO_2 emission convergence among neighboring countries.

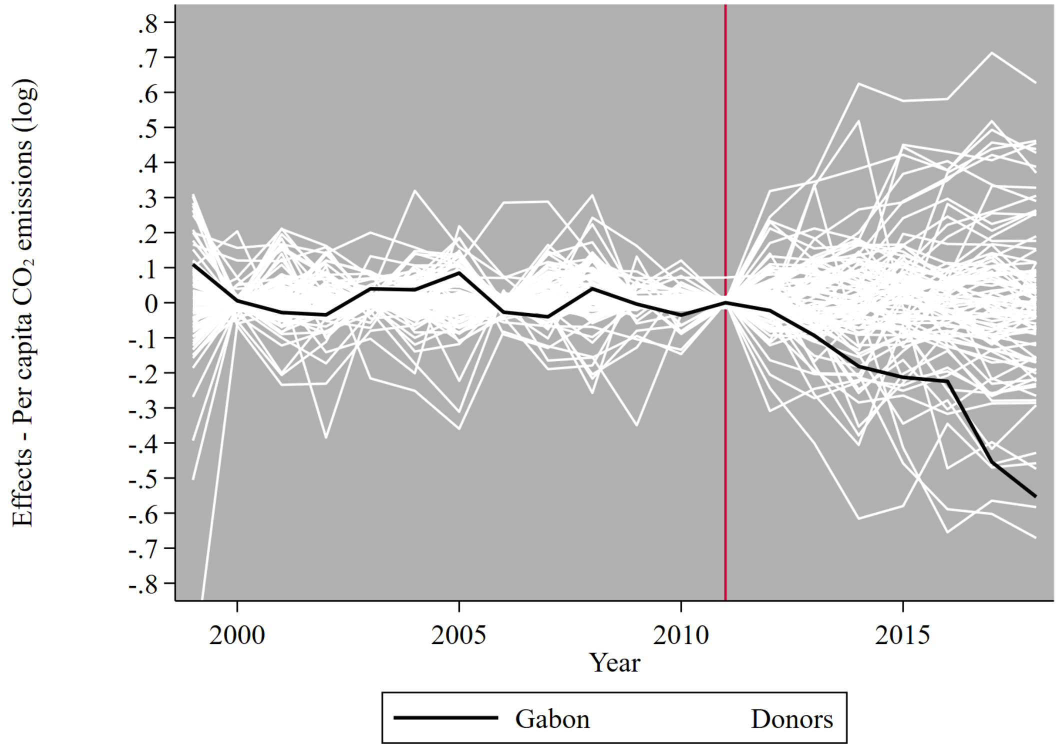

Figure 4: Permutations gap test in Gabon versus placebo gaps of donor pool countries. Emissions gap in Gabon are close to zero before the policy intervention. After the policy enactment, the negative gap increases and is larger than the majority of the controls.

If one were to run the SCM estimation for a non-treated country of the donor pool, the procedure would be labeled a placebo because no policy change actually occurred there. In theory, the impact measured from these placebos should be close to zero on average. This much be apparent from a symmetric distribution of effects around zero after the policy. The SCM algorithm repeats this procedure for all the donor pool countries, and then compares the post-treatment path of Gabon to all the placebos to see if Gabon stands out. Figure 4 show these placebo tests. In the pretreatment period, Gabon's effect is close to zero. After the policy the measured effects are on average null as shown by the symmetric distribution around zero. Gabon however, shows a clear reduction that goes increasing each year. By 2018, the measured effect in Gabon is one of the largest in the donor pool.

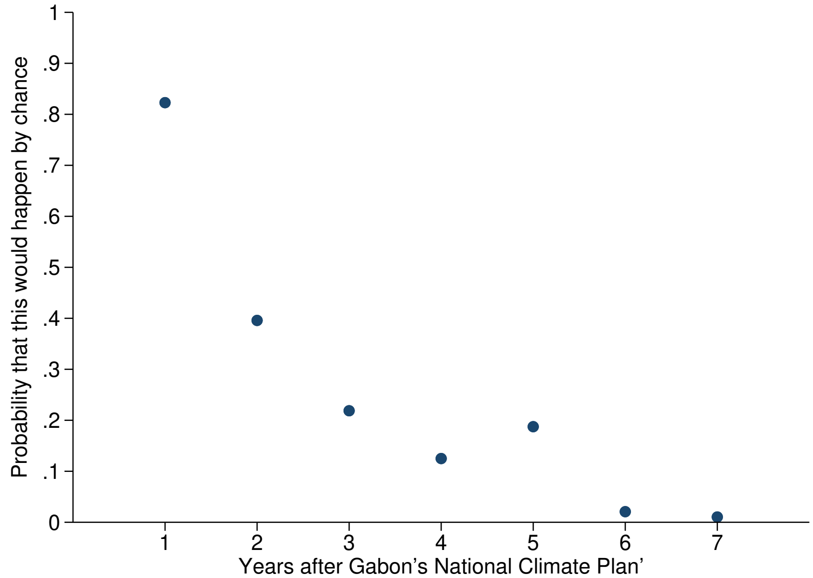

Figure 5: Standardized P-values of the policy. The share of placebo effects larger than Gabon falls with time. Six years after the policy, the emissions reductions are strongly statistically significant.

Figure 5 shows the standardized p-values obtained from the placebo permutations.[19] Abadie et al. (2010) advise comparing the standardized p-values against a 10% threshold. With very large p-values, we cannot statistically distinguish the estimated effect from pure chance. Directly after the policy change, the effect on Gabon's carbon dioxide emissions is not significant, as seen with the large p-value. However, this gradually changes for each year until 6 years post enactment when the p-values are essentially zero pointing to strong statistical significance. This is an interesting observation that raises the question of timing in such environmental policies.

6 Sensitivity analysis

In this section, we conduct a number of robustness checks of our results. We begin by testing whether our results are driven by Singapore, given the large weight of the country in the synthetic control. We then experiment with an alternative donor pool to check whether our results are affected. Finally, we formally verify the quality of our pre-period fit compared to other comparison units.

[19] Abadie et al. (2010) obtain standardized values by dividing all effects by the corresponding pretreatment match quality. Galiani and Quistorff (2017) reemphasize that these "p-values" help assess significance, but do not have the common interpretation as in regression analysis.

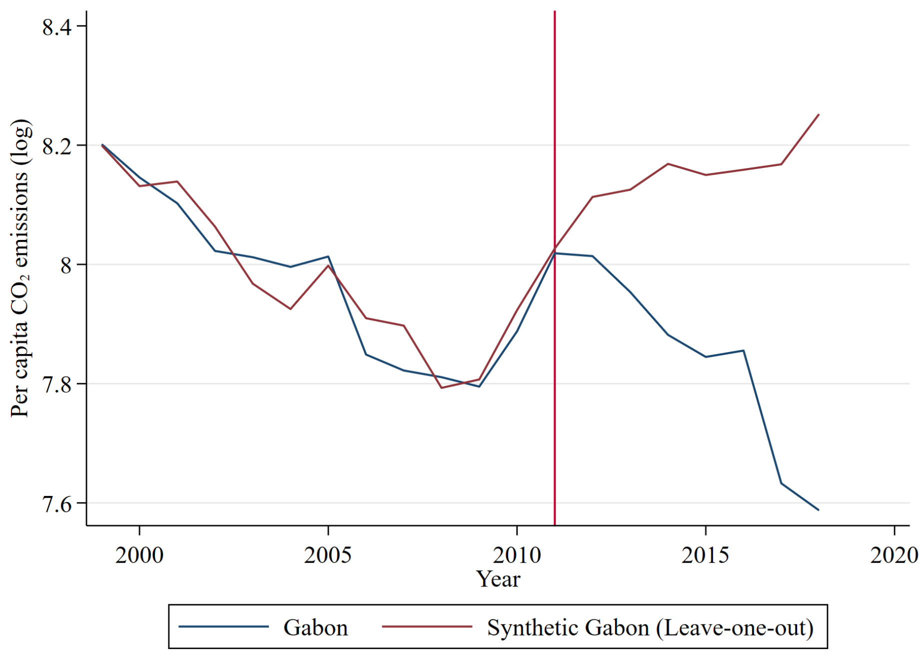

Figure 6: Trends in CO_2 emissions of Gabon versus synthetic Gabon (1999-2018) leaving Singapore out. Before the policy shift, Gabon and its synthetic control trend are close. The leave-one-out output is similar to the previous one, but the gap is even larger.

One obvious concern with the original result is the size of the weight allocated to Singapore in Gabon's synthetic control. Although the two countries have very similar pre-treatment CO_2 emissions trends, perhaps the country may not be an adequate comparison unit due to other differences, especially development level and geography.

To address this, we conduct a "leave-one-out" estimation without Singapore. Figure 6 shows that we obtain comparable but relatively larger results. The new donor pool now consists of Zimbabwe (0.442), Czech Republic (0.41), Bahrain (0.093), Nepal (0.044) and Belize (0.011) and the percentage point decrease is estimated to be -37.77 % compared to -24.16% when including Singapore. In other words, after removing Singapore which is a relatively more industrialized country from the donor pool, the estimated effect is significantly larger. We pursue this potential issue by placing further restrictions on the comparison pool.

Another possible concern with our results is the donor pool size and composition. Although Gabon does have many distinctive economic and historical features, it is located in sub-Saharan Africa. Thus, including Asian, Middle Eastern or European countries in the comparison group may not be adequate. We investigate this avenue by restricting the donor pool to only sub-Saharan African countries.

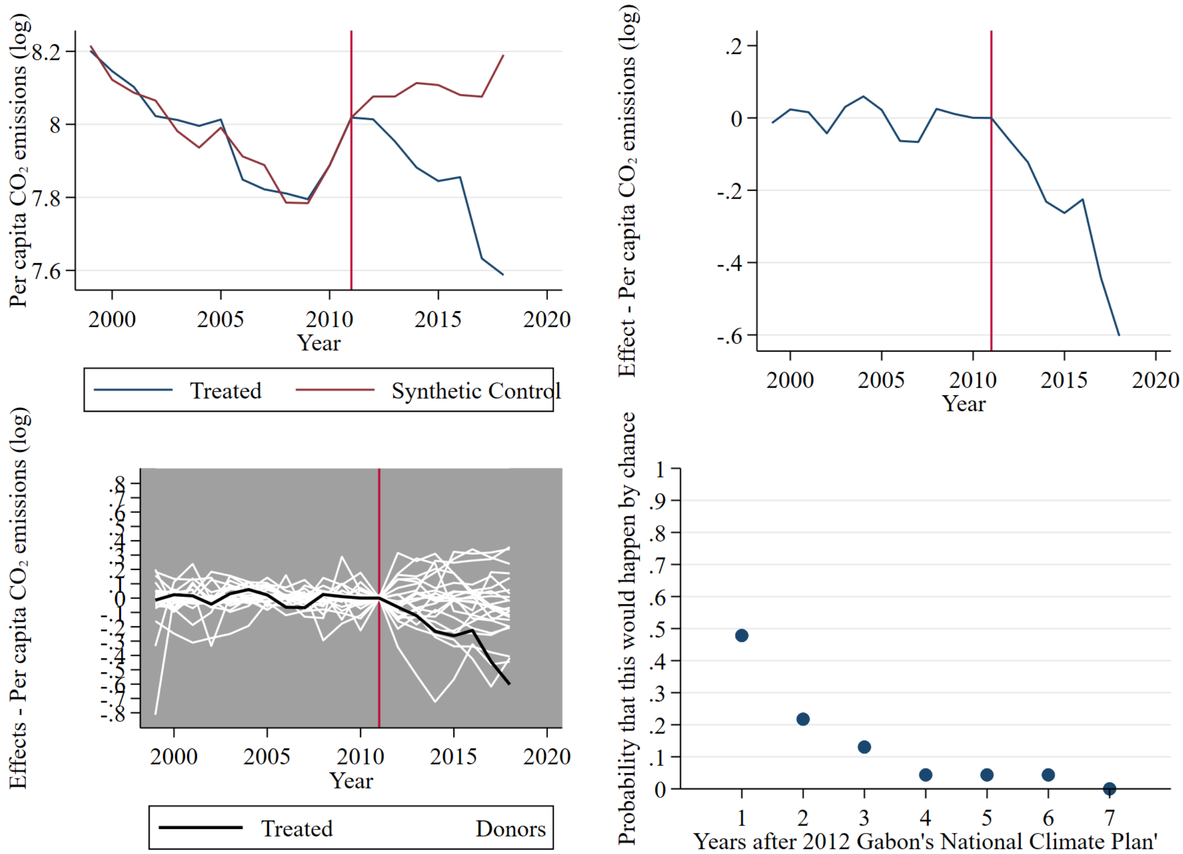

Figure 7: SCM among 24 sub-Saharan countries. The effect are largely similar in the smaller donor pool of subsaharan countries. Treatment effect average an annual 31.46 lower per capita carbon dioxide emissiosns.

In addition, there is also the issue of vicinity and spill-over effects. Perhaps Gabon's reductions in emission may have affected its neighbors. To circumvent this problem, we exclude neighbors countries from the Congo Basin including Cameroon, The Democratic Republic of Congo, The Congo, Rwanda, Burundi and the Central African Republic. This reduces the donor pool to 22 countries.[20]

Figure 7 shows the result of this exercise. As expected, the pre-period match of Gabon and its synthetic control is still good. However, it is also apparent that the estimated impact of the policy is somewhat larger when comparing Gabon to only sub-Saharan countries, as opposed to the larger donor pool. The divergence between the actual Gabon and its synthetic control is such that the majority of the standardized p-values from placebos runs fall under 10% and several are closer to zero. The new synthetic unit comprises South Africa (0.476), Botswana (0.268), Zimbabwe (0.256).

[20] We also reestimate the effect of the policy, including all other countries of the Congo Basin. The results are unchanged, and none of the afore mentioned countries is selected by the algorithm as a donor.

Table 4 show the annual effect estimates. With this new synthetic control, the estimated reduction in CO_2 emissions from 2012 to 2018 is -31.46% or -0.96 less metric tons of CO_2 per person per annum. Aggregating this over the whole population for the entire posttreatment period gives an estimated cumulative -11.7 million of metric tons decrease of CO_2 emissions as a result of the policy. In comparison to the previous estimate, of -10.41 million metric tons, this is larger.

Table 4: The impact of the 2012 Gabon National Climate Plan: Donor pool in sub-Saharan Africa

Year	2013	2014	2015	2016	2017	2018	Total
Percentage point difference (%)	-12.25	-23.15	-26.28	-22.51	-44.29	-60.29	-31.46
Per capita effect (metric tons)	-0.41	-0.76	-0.84	-0.71	-1.26	-1.79	-0.96
National effect (millions of metric tons)	-0.74	-1.43	-1.64	-1.44	-2.62	3.81	-1.95

Notes: All estimated effects are computed as the difference between Gabon's observed outcome and the synthetic control unit for each year following the policy intervention.

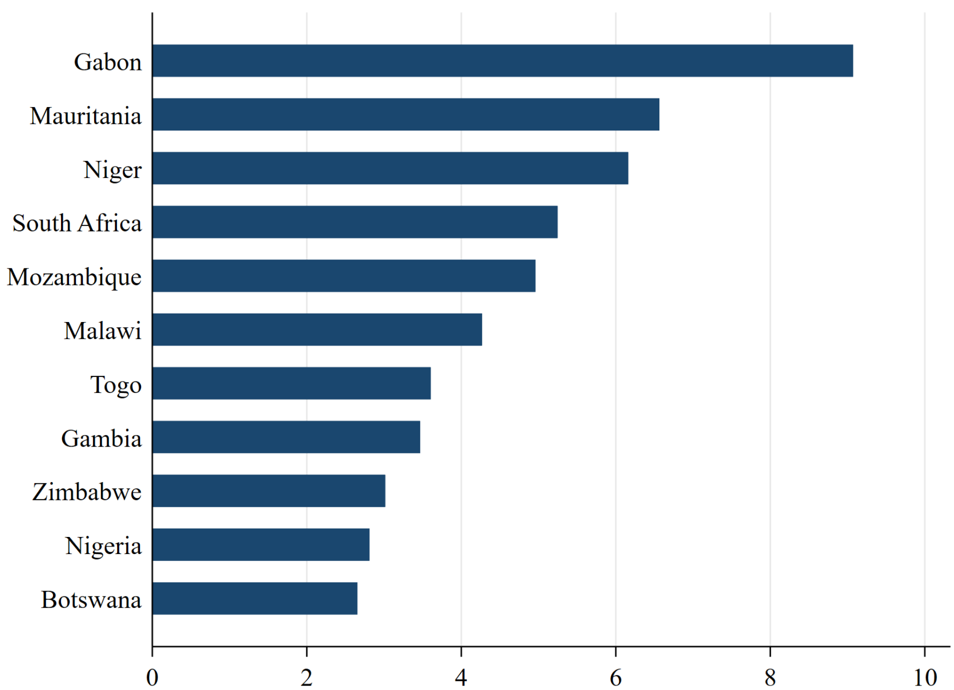

Figure 8: Ratio of post to pre-treatment RMSPE. Gabon's post to pre RMSPE ratio is the largest in the sample, pointing to the significant effect of the National Climate Plan.

To assess the quality of the pre-period match, we compute the root-mean-square prediction error (RMSPE) for goodness of fit:

$$RMSPE = \sqrt{\frac{1}{T_0}\sum_{t=1}^{T_0}\left(Y_{1t} - \sum_{s=2}^{J+1} w_i Y_{it}\right)^2}$$

where Y_{1t} is CO_2 emissions in Gabon at time t, T_0 is 2011, w_i is the weight on country i of the donor pool and Y_{it} is the outcome in country i at the same time. The intuition of this procedure is as follows. If Gabon closely matches its synthetic control and then significantly deviates in a way that is unlike donor pool placebos, then the ratio of the post/pre period $RMSPE$ should reflect this fact and Gabon should stand out. In Figure 8 the ratio of post-treatment to pre-treatment RMSPE is 9.07 which is above the 90th percentile in our sample. We also obtain standardized p-values for each year posttreatment which we show on Figure 5.

7 Did Gabon's output fall due to the climate policy?

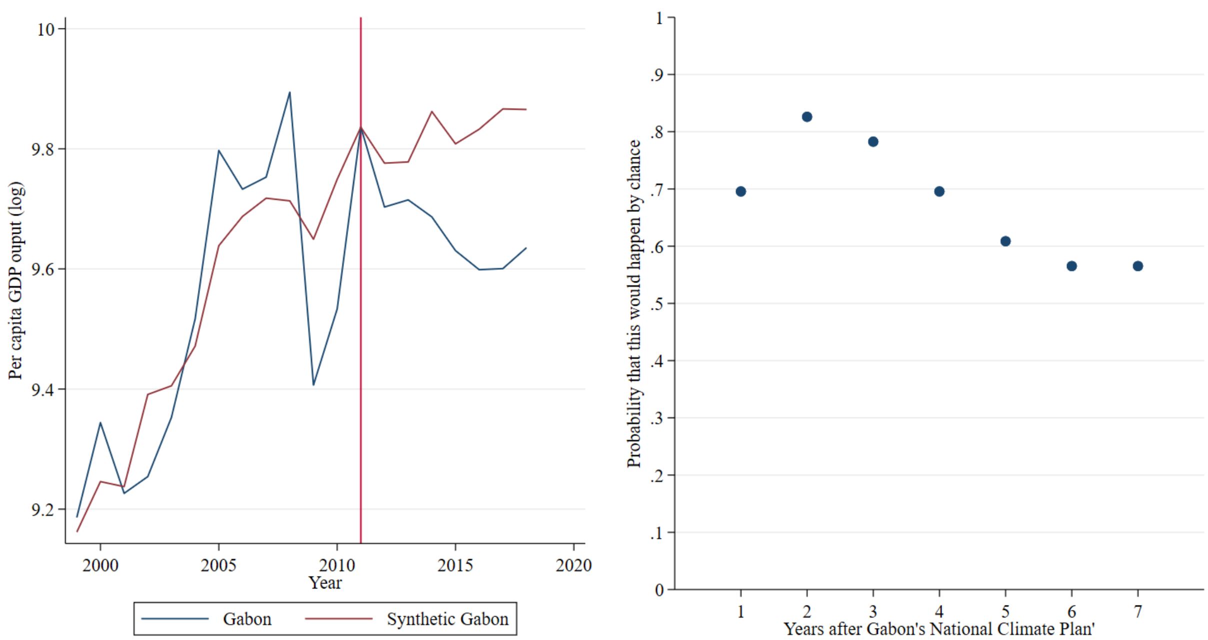

Figure 9: Per capita income Gabon vs. synthetic Gabon. Gabon's per capita income has experience large fluctutation in recent decades. The estimated loss in output following the climate plan is not statistically significant.

It is also unclear whether the policy significantly impacted output. Gabon had been an emerging economy with historical reliance on oil production and exports. Thus, flaring regulations may have stomped economic growth. In this section, we investigate the impact of the intervention on the per capita output of Gabon compared to other sub-Saharan African countries.

Figure 9 shows the comparison between the per capita output of Gabon and its counterfactual. Three elements are remarkable. First, the per capita output of Gabon appears to have been subject to large swings in relatively short periods of time. This may be explained by the importance of oil prices in determining national output. Given recent global oil price volatility (Kilian, 2010), this is to be expected. Second, the per capita output of Gabon, is lower than its counterfactual path at an estimated -6.45% lower than without the policy change. However, the permutation analysis shows that this effect is not statistically significant, and cannot be distinguished from chance. Overall, we interpret this results as pointing to a limited adverse effect of the policy on national per capita income.

8 Conclusion and discussions

This study commenced with the loud international call for climate change mitigation and adaptation. Mitigation refers to "the anthropogenic intervention to reduce the sources or enhance the sinks on GHGs such as carbon dioxide, methane, and nitrous oxide" (Somorin et al. (2012), p. 288), whereas, adaptation refers to "any adjustment in natural or human systems in response to actual or expected climate change" (Somorin et al. (2012), p. 288). Gabon's 2012 National Climate Plan did both successfully, an outstanding outcome in sub-Saharan Africa.

The policy was part of a larger vision to develop a sustainable and emergent economy. While Gabon has abundant natural resources and a small population, income inequality and poverty had remained pertinent issues. Much of the literature on Gabon discusses the country's difficulties to sustain a diversified economy, thus further contributing to environmental degradation (Soderling (2002), Dobdinga (2015)). But, Gabon not alone facing these challenges, as they persist throughout sub-Saharan Africa and other developing countries. However, we conjecture that the true value of this study lies in its ability to act as a meaningful case study for other countries with similar cultural, geopolitical and economic challenges seeking to deploy methods that made Gabon's National Climate Plan successful.

We estimated that following the policy enactment, per capita carbon dioxide emissions were reduced by at least 24.16% after 2012. These reductions can be attributed to strategic land use planning, gas flaring regulations, strong monitoring through Gabon's National Observation of Natural Resources and Forests (SNORF), and continuous open dialogue with the UNFCCC.

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