The impact of Austria's climate strategy on renewable energy consumption and economic output

Abstract

In the midst of the energy crisis being felt throughout many parts of Europe, this study aims to investigate the full impact of Austria's 2002 continent leading climate strategy on national renewable energy consumption. Using the synthetic control method (SCM) to select a group of comparable countries, we estimate that renewable energy consumption rose between 2.41% and 4.86% annually (over a 12-year period) as a result of the policy. In addition, per capita output did not fall, contrary to some predictions. The study contributes to the literature on environmental governance, policy discourse, and climate. It also provides critical policy elements in the roadmap toward energy security for other European countries.

Keywords: Climate change, renewable energy, Austria, synthetic control method.

1 Introduction

Energy represents a critical driver for the social and economic development of nations across the world. "Oxygen of the economy" as coined by the World Energy Forum perhaps best encapsulates its real value (Yergin and Gross, 2012), and access to it has notably been referenced by the Sustainable Development Goals of the United Nations – as a necessity (UN SDG, 2022). However, over the last few decades, there has been a steady increase in total energy consumption, globally.

In this regard, the International Energy Agency (IEA) noted an increase from 4,243 million tons of oil equivalent (Mtoe) in 1971 to nearly 10,000 Mtoe in 2018 (IEA, 2020). These statistics also point to the dependency on fossil fuels (Yergin and Gross, 2012), particularly in the European Union. These consumption trends combined with fossil fuels use have contributed to the degradation of the natural environment by increasing greenhouse gas emissions and accelerating global warming. Noteworthy to mention and in the context of this paper, these energy consumption trends have been a result of past energy policies in the many regions across the world, including Europe.

However, to mitigate the effects of energy consumption on the environment, several initiatives were set at global and regional levels. For example, at a global level, the Kyoto Protocol of the United Nations Framework Convention for Climate Change (UNFCCC) was adopted in 1997, providing guidelines for the development of policies and measures by parties (signatory countries) necessary to achieve quantifiable emission limitations and reduction commitments (UNFCCC, 1997). On the regional front, several regional communities of countries also moved to set their own climate targets for the reduction of greenhouse gas emissions in line with Kyoto Protocol commitments. As these mitigation initiatives evolved, in 2007, the European Union (EU) Commission developed the bloc's climate framework and set a target to reduce GHG emissions by 30% by 2020 as compared to 1990 levels (European-Union, 2007). In this regard, the development and use of renewable energy resources was among the main measures recommended for the achievement of global and regional climate ambitions and commitments set out in the above-mentioned framework (UNFCCC, 1997). In this respect, several strategies were put in place at the country level, with diverse effects on energy consumption patterns, particularly on renewable energy consumption.

As a result, in part, across the EU, renewable energy consumption played a significant role in reducing GHG emissions as the bloc strived to achieve climate neutrality by 2050. The EU reached 21.3% share of renewables in final energy consumption in 2020 as compared to 10% in 2005. Also, GHG emissions were on average 31% lower in 2020 as compared to 1990, surpassing the bloc's 2020 emissions reduction target (EEA, 2012). Despite this notable progress, energy-related emissions from power and heat generation, as well as commercial, industrial, residential and transport energy consumption still account for most of the bloc's total GHG emissions which stood at approximately 3.4 million kilotons of CO_2 equivalent in 2019 (World Bank data). Compounding this issue further, emerging energy security and geopolitical issues are threatening to reverse some of the gains made in renewable energy consumption and GHG emissions reduction in the EU over the last two decades. Most recently, and perhaps most notably, the Russia-Ukraine conflict has disrupted global energy supply and laid bare the vulnerabilities of the EU's energy supply system. EU member states, which still rely heavily on imported fossil fuels as the main source of primary energy supply, are facing a harsh reality of rapidly increasing fuel prices and a potential risk of energy shortages.

The current "energy crisis" has moved some EU member states including Germany to consider reactivating, retired, highly polluting coal-fired power plants in order to decrease reliance on Russian supplies (Connolly et al., 2022) just to get through the winter. Other short-term measures undertaken by member states include sourcing fuels from other (more trusted) countries, while also encouraging energy saving measures and possible rationing in homes and industries. However, in order to build a more resilient energy supply system in the long term, EU member states need to move swiftly to reduce dependency on imported fossil fuels. Diversifying energy resources by accelerating the transition to renewable energy can help to achieve this goal, while at the same time ensuring that commitments of member states to reduce carbon emissions and combat climate change are not compromised. Such progress requires bold policy decisions backed up by corresponding policy measures.

In this regard, the experience and leadership of Austria in promoting renewable energy since the early 2000s can provide valuable lessons for other EU countries seeking to accelerate the deployment and use of renewable energy resources.

Austria's "Climate Strategy" was adopted in January 2002 defining a clear roadmap for the reduction of greenhouse gas (GHG) emissions by 13% compared to 1990's level under the Kyoto protocol (Grantham Institute, 2015). The climate strategy set out a series of measures focusing mainly on reducing energy-related carbon dioxide emissions in sectors such as space heating and transport. The strategy put renewable energy and energy efficiency at the center of Austria's climate agenda (OECD/IEA, 2003). Following the launch of the strategy, Austria experienced an unprecedented increase in the share of renewable energy consumption in the total final energy consumption (TFE) This was far beyond the average EU community's share of renewably energy consumption in TFE consumption that only recorded an increase from 9% to 17% during the same period, or even Germany that recorded an increase from 5% to 14%.[1] This placed Austria in the top five countries in the EU with regard to the share of renewable energy consumption in TFE consumption. This prompts the obvious question, how was this achieved? As such, In this study, we seek to identify the key policy factors that contributed to Austria's astounding increase in renewable consumption (from 2002 – 2014), in hopes of generating a policy road map and best practices that can be utilized by other EU countries, particularly Germany, to sustainably tackle current energy challenges.

2 Policy background

Austria's renewable energy policy emerged and started to take shape in the late 1990s and early 2000s. Concrete policy measures to promote renewable electricity in Austria were first introduced in 1998 when the Federal Electricity Act required that grid operators take in electricity produced from renewable sources (Pfluglmayer et al., 2008, p. 199). In the early 2000s, two other (major) energy policy interventions were undertaken namely: i) the liberalization of the electricity and natural gas sectors, and ii) the development of a comprehensive strategy to meet Kyoto Protocol commitments on greenhouse gas (GHG) reductions (OECD/IEA, 2003).

Electricity sector liberalization in Austria was achieved through the amendment of the Electricity Industry and Organization Act in 2000. The amendment granted electricity consumers a right to choose their supplier, making Austria one of the first five countries in the European Union to grant this right. Austria's climate strategy was adopted in 2002 as a nation-wide plan – developed jointly by federal and regional governments as well as private sector players – to reduce greenhouse gas emissions following the country's ratification of the Kyoto Protocol in the same year. Under the Kyoto Protocol, Austria committed to reduce GHG emissions by 13% below 1990 levels by 2008 – 2012. The climate strategy set out a series of measures intended to achieve these commitments, focusing mainly on reducing energy-related carbon dioxide emissions in sectors such as space heating and transport which were projected to contribute at least 50% of the emissions cuts. The strategy placed renewable energy and energy efficiency at the center of Austria's climate agenda:

[1]Data retrieved from World Bank Indicators on renewable energy as percentage of primary energy consumption.

- *Space heating and small/individual consumption*: As early as 2002, the need to transform the space heating sector to use sustainable energy was recognized and included in Austria's climate strategy. The strategy introduced several energy policy interventions for the space heating sector including requirements/mandates for thermal improvement of existing building stock, enhanced technical standards for new buildings, increasing share/use of renewable energy sources in space heating, increasing boiler efficiency, fuel switching and demand-side measures to reduce space heat demand. Similar measures were introduced in the Austrian Energy Strategy of 2010 requiring acceleration of building refurbishment and replacing fossil-based heating systems with renewable heating systems.

- *Electricity generation/supply*: From the early 2000s until 2014, several policies were enacted which introduced several measures aimed at increasing renewable energy integration in Austria's power sector. The Green Electricity Act of 2002 (as amended in subsequent years) was one of the earliest policies to support the development of renewable electricity in Austria. The Act introduced several policy interventions, key among which was the feed-in tariff scheme which obliged power utilities to purchase electricity from selected renewable energy technologies at above-market tariffs which are determined by the government. The utilities were then compensated for the additional expenses associated with the purchase and sale of green electricity. To support the compensation scheme, the Act also established a mandate for all consumers connected to the public grid to make a subsidy contribution, collected by network operators, towards covering additional expenses associated with green electricity access. In 2011, a new feed-in tariff decree was issued which set tariff rates under the scheme at between €0.05/KWh to €0.25/KWh for electricity generated from different renewable energy sources. The Green Electricity Act also provided for investment grants and green electricity bonuses for certain types of investments in renewable electricity including high efficiency co-generation installations. A 2011 amendment of the Act also set the target of 1000 MW Hydro, 2000 MW Wind, 200 MW Biomass and biogas, 1200 MW Solar energy production increase by 2020 against a 2010 baseline. Other policy measures introduced required electricity suppliers to source a minimum of 8% of their electricity from small hydropower plants (lt; 10 MW) and 1% (increasing to 4% by 2007) from other renewable energy technologies such as solar, wind and geothermal facilities (excluding large hydropower and biomass). Austria's climate strategy of 2002 (as amended in 2007) also set a target of 80% of total electricity production to come from renewable sources by 2010, increasing to 85% by 2020.

- *Transport/mobility*: Carbon dioxide is the most prevalent GHG emitted in Austria and the majority of CO_2 emissions come from energy-related activities especially in the transport sector. In a move to reduce CO_2 emissions from Austria's transport sector, early policy interventions promoted renewable energy (particularly biofuels) and energy/fuel efficiency in road transport. Energy policy measures in the transport sector as envisioned in the 2002 climate strategy included financial instruments for motor vehicles (i.e., fuel consumption- based registration taxes and road tolls) and improvement of fuel quality and promotion of biodiesel and technology innovation. In 2003, the (EU) transportation of biofuels directive was enacted, which obliged/mandated all companies putting fuels in circulation to replace 2.5% of the total fuel supply with biofuel. The share of biofuels was increased in 2007 to 4.3% and the EU-wide target of 5.8% was achieved in 2008. Austria's Mineral Oil Act which was enacted in 2007 provided tax concessions for fuels with biofuel share of at least 6.6% and 4.6% for diesel and petrol respectively. However, Austria issued its fuel ordinance amendment in 2008 limiting the share of biodiesel in fuel supply to a maximum of 7%.

3 Social, economic and environmental policy impacts

3.1 Environmental impacts

As early as just 2004, already, the contribution of renewable energy technologies in Austria reduction of carbon dioxide (CO2) emissions was 11.9 million tons. This trend observed in early 2000s was further confirmed during the next few years with the additional CO2 emissions reduction as a result of the country's political efforts in research, development and promotion of the use of renewable energy sources. Driven by the Directive 2009/08/EC of the European parliament, and aiming to promote the use of energy from renewable energy sources, Austria recorded in 2011 and 2012, respectively, total net estimates of greenhouse gas emissions savings of 18.8 and 18.1 million tons in the electricity sector; 9.4 and 10.3 million tons in the heating and cooling sector; and 1.7 and 1.6 million tons in the transport sector (Bmwji, 2014) – clear impact and benefit to the natural environment.

3.2 Social impacts

The implementation of the climate strategy initiated in early 2000s, and its compound effects on the adoption and consumption of energy from renewable sources significantly contributed to the sustainable health and wellbeing of Austrian society. Specifically, the adoption of energy use from renewable energy sources fostered the development of a decentralized application of energy for different applications including electricity, heat, and cooling (Kranzl et al., 2013). In turn, this encouraged a set of specific support schemes offered by regional and national authorities for the development of renewable energy source based-heating system across the country. This support positively impacted sectors such as the residential and building sector (domestic and non-domestic), and even the agricultural sector.

Moreover, the decentralized nature of the applications of renewable energy systems allowed for energy commodities to different parts of the country, particularly in rural areas, which prompted development of new renewable energies markets and the associated job creation, both at regional and national levels (Faninger, 2006).

In addition, the promotion of renewable energy sources and the development of decentralized units across the country contributed to increasing energy security in the country and in different regions. For example, in 2004 the district of Güssing became the first energy-independent district in Austria, with a renewable energy biomass power plant and a biodiesel plant based on rapeseed oil. Similarly, other regions like Burgenland, managed to achieve 100% electricity supply from renewable wind energy sources (Wurster and Hagemann, 2019).

3.3 Economic impacts

As generally acknowledged in the literature, the development of the renewable energy (consumption) sector through the subsequent production system is accompanied by a series of economic benefits for the economy. In Austria, renewable energy consumption in total final energy consumption rose from 9.9% in 2003 to about in 15.94% in 2013[2], with the development of diverse renewable energy infrastructures in different sectors (electricity, heating, transport, etc.) throughout this period. In the electricity sector, the renewable energy sources accounted for 15,785 MW capacity in the country mix, with large hydro accounting for over 10 MW (Faninger, 2006). This figure drastically changed in 2012 to 16,818 MW, with a notable increase of other renewable energy sources besides large hydro

[2]Statistika database. https://statcube.at/statistik.at/ext/statcube/jsf/tableView/tableView.xhtml, Accessed on 19.08.2022

power due to deployed policies. As an example, the market of solar PV recorded an unprecedented increase from 9 MW to over 330 MW in 2012, while the sector of wind power increased from 560 MW to more than double (1.3 GW) during this period (Sebanz et al., 2013) In sum, by the early 2000s Austria's renewable energy sector saw an increase of its market value from 1.46 billion euros in 2004 to about 5.7 billion euros in 2013 due to policies in place (Faninger, 2006; Günsberg, 2016). This market increase also significantly impacted job creation, with over thirty-eight thousand full time equivalent jobs created in 2013 in the renewable energy space (Günsberg, 2016). And if we consider the indirect jobs created along the value chain of biomass from its preparation to its use as energy carriers in different processes, the impact is even more significant.

In sum, these impacts are clearly significant, however, further empirical evidence is warranted in determining the true effects of the policy. As such, the following section is dedication to the analysis.

4 Data

Here, we present an overview of our data. . We use annual data available between 1990 and 2015.[3] We focus on the Organization for Economic Co-operation and Development (OECD) countries, as Austria is a member, but we also have data on more non-members. Lower income countries and several middling income countries, based on recent World Bank rankings, are not featured, mostly due to data availability. The OECD grouping was chosen for economic and political comparability (Apergis and Payne, 2010; Jin, 2022). There is also geographical relevance, as many members are also European countries.[4] There are a total of 47 countries and 30 OECD members, including Austria.[5]

Data on renewable energy consumption originates from the World Development Indicators (WDI).[6], which is our variable of interest. The initial policy had targets for growth in renewable production of electricity as opposed to all energy output, which would include gasoline, jet fuels, and others. The objective was to encourage renewable energy adoption by supplying it more readily. This process

[3]Other climate related policies were discussed in the 2010s. An important one was "The Strategy for Adaptation to Climate Change" enacted in 2017. We end our analysis in 2015 to minimize confounding effects. In other versions of the analysis, we expand the data span to 2019. These results are available upon request.

[4]We also use this grouping and find similar results.

[5]See appendix for the exhaustive list of countries and their grouping.

[6]See World Bank data on renewable consumption. The exact name of the series is renewable energy consumption (% total final energy consumption). Renewable energy categories in Austria include the common mix. In order of importance, they are hydropower, wind, solar, biomass and geothermal (https://www.apg.at/). Although generally controversial in terms of classification, the case of nuclear energy is worth mentioning. Austria has a history of non-nuclear energy generation and does not produce any.

of course was not coercive. We deliberately decide to study the effect on Austrian consumption of renewables as opposed to production. This is important since it is unclear whether the newly established incentives translated to causal consumption behavior shifts.

Figure 1: Trends in renewable energy consumption in Austria versus OECD countries.: The vertical line represents the year of policy enactment. Even prior to the policy, Austria is already a large renewable energy consumer. Energy consumption increases after 2002 at a faster rate than the sample average.

Figure 1 shows the share of renewable consumption in Austria as compared to the OECD average overtime. Prior to 2002, about 25% of energy consumption was already covered by renewable sources. This proportion had been relatively stable over time, until 2002, the year of policy implementation. The other insight aside from Austria's noticeable growth in consumption, is that the country is well above the sample average. The other insight is that aside from Austria's noticeable growth in consumption, the country is well above the sample average. To put this observation into perspective, we can consider the Netherlands, Ireland and Italy, which have also raised their renewable energy consumption over the years (Mulder and Scholtens, 2013; Connolly et al., 2011; Magazzino, 2017). In 2002 renewable respectively covered only 1.92%, 2.25%, and 5.6% of total final energy consumption. In other words, the Austria level of renewable utilization was already remarkable. The third observation from Figure 1 is that renewable energy consumption first falls after the policy enactment, but then rises after 2003 to reach over 35% by 2014. The trend in the OECD average shows that other countries had been increasing renewable energy consumption over time, although Austria's grow stands out.

From the World Bank database, we also collect data on urbanization. This variable represents the percentage of urban population as a share of the total. Salim and Shafiei (2014) investigates the impact of urbanization on renewable energy consumption among OECD countries (1980-2011). The empirical analysis shows that high rates of urbanization are associated with increased consumption of non-renewable energy, although not causal. Nathaniel et al. (2020) focuses on a group of emerging economies instead and finds that urbanization is one of the main drivers of environmental degradation along with non-renewable energy utilization. Traditionally, more urbanization has been linked with higher overall energy consumption, rather than only one category (Jones, 1991; Sheng et al., 2017).

The rest of our data originates from Penn World Tables 10 (PWT10). We gather data on per capita GDP and the rate of depreciation of capital. Le et al. (2020) studies a panel of 55 countries to clarify the key elements in renewable energy deployment. The study shows that financial development is one of the most important variable, so we include GDP per capita into our analysis. Other researchers in climate policy have routinely included this variable as a predictor (Andersson, 2019). Depreciation rate of available capital has also been considered an important variable in renewable energy consumption and economic efficiency (Halkos and Tzeremes, 2013).

5 Empirical methodology

5.1 The synthetic control method

Difference-in-differences (DiD) methods have been extensively used in comparative studies to estimate the influence of various policy. The approach features panel data and relies on the parallel trend assumption to draw a comparison between treated and control units. The central assumption is that the two groups have had a comparable evolution prior to the policy shock. Based on this assumption, deviations from the "average" comparison units are attributed to the policy and thus estimated.

In practice, this assumption is difficult to verify, and the control units can be chosen arbitrarily among the available units.[7] The synthetic control method waives this assumption and relies instead

[7] Ryan et al. (2015) conducts Montecarlo simulations to estimate the effect of a fictitious policy using DiD methods. The findings show that there is substantial variation in performance of estimation depending on the pre-intervention control groups chosen. In general, control groups are chosen based on similarity, which is difficult to formally define. For example, Turner and Blagg (2018) studies the impact of Kansas income tax cuts on employment. The comparison group is made of neighboring states. This choice has advantage, but also presents problems due to potential spill-over effects and business relocations.

on a simple algorithm to choose the comparisons units. This section briefly presents the synthetic control method intuition and algorithm based on Abadie et al. (2010, 2015) as applied to our study of Austria's energy reform[8].

The SCM is based on three assumptions (Bouttell et al., 2018; Wallimann, 2022). First, we assume that renewable energy consumption in Austria (the treated unit) and the synthetic counterpart (the constructed unit) are similar before the policy change. In general, this is justified by the similarity of the countries in the donor pool. In our case, we begin by limiting the analysis to other OECD countries. The second assumption is that no spill over effect occurs for other countries. This is plausible as well in our context, given that Austria has historically been an energy importer. This reduces the odds for potential spillover. The last assumption is that there are no contingent external changes or policies that impact the countries in the control group. This assumption deserves a more thorough discussion in our context. Although few countries had policies with exactly the same provisions for renewable energy production on the same year, several OECD members have undertaken some form of action to transition toward clean energy production. We address this in more detailed in the sensitivity analysis section. We do this by considering alternate comparison pools less likely to face this difficulty. For now, we emphasize that we thus consider our first approach as a sort of "lower bound" or most conservative estimate.

Each country in the donor pool is indexed by n and assigned a non-negative weight w_n (except Austria) such that all weights sum up to one. The weights defining a given synthetic control W^* are chosen to minimize the sum of squares:

$$\|X_1 - X_0 W\|_V = \sqrt{(X_1 - X_0 W)' V (X_1 - X_0 W)}, \tag{1}$$

where X_1 is a vector of predictor variables for Austria, 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.[9] 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. In other terms, the SCM uses a specified regression model to minimize

[8] In the appendix, we provide an even more detailed presentation of the technical aspect of the implementation.

[9] Bohn et al. (2014) provides extensive details regarding the STATA procedure used to obtain the V matrix. Based on Abadie and Gardeazabal (2003) the algorithm uses a default regression-based measure of V where matching variables that are strong predictors of the dependent variable are given more weight and the elements of V are normalized such that they sum to 1.

the pretreatment distance between the actual Austria and a synthetically generated one. This method essentially creates a counterfactual comparison unit that is most similar to the treated unit. This synthetic control is made up of a mix of comparable countries, in which each country's importance is based on the algorithm assigned weights w_n.

Abadie et al. (2010) argues that in several comparative studies, it is uncertain whether the control group adequately generates the counterfactual path of the outcome variable if the policy did not occur. The SCM method has gained in popularity in recent years for several reasons. It is less arbitrary than many analogous methods of comparative studies because it uses this data driven selection process.[10] 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 Austria and its synthetic control overtime. This makes it a bit more intuitive. Of these advantages, the last one is sometimes thought of as also the one that represents a challenge. In practice, the SCM does not provide an R^2 neither standard errors of the estimate nor other comparable statistics. Instead, to establish significance, one must use placebo permutation procedures to compare the treated unit to the other countries. This yields a p-value that evaluates the chances that the estimated effect is the product of chance.

5.2 Results

Table 1 compares the pretreatment values of keys predictors for Austria to their synthetic counterpart, as well as the OECD countries' central tendency.[11] These variables are the one that enter the regression analysis driven process of weight selection. The characteristics used for prediction are lags of the national share of renewable energy consumption (1997, 1999 and 2001), the per capita GDP, the percentage of urban population and the annual level of depreciation of capital. For the majority of the predictors, except urban population, Austria and its synthetic counterpart are close to each other.

[10] For example, the well-known study of the impact of the Mariel boatlift on the Miami labor Market (Card, 1990) uses a combination of four US cities as a control group (Atlanta, Los Angeles, Houston and Tampa) to approximate the counterfactual for Miami. Montalvo (2011) argues that the justification of the choice of these cities is not based on any formal specification methodology, but rather on an argument of similarlity: "These four cities were selected both because they had relatively large populations of blacks and Hispanics and because they exhibited a pattern of economic growth similar to that in Miami." In contrast, this choice is data driven in the SCM framework.

[11] This is the simple arithmetic mean. Note however that histograms of renewable energy consumption prior to the reform are right skewed and show a significant spread even within the OECD. In 2001, the United Kingdom recorded the lowest consumption of renewable energy at just 0.85% of total final energy. Iceland in contrast was the largest consumer at 62.11% of renewable energy.

Table 1: Comparison groups

Variables	Austria	Synthetic Austria	OECD average
Ln(GDP per capita)	10.36	10.50	10.34
Urban population (%)	61.45	70.11	77.71
Depreciation of capital (%)	3.71	3.72	3.6
Renewable consumption (%) (1997)	24.87	25.04	17.01
Renewable consumption (%) (1999)	26.43	25.82	17.20
Renewable consumption (%) (2001)	25.48	25.74	17.28

Notes: All variables except renewable consumption are averaged for the period 1990-2014. GDP per capita (log) is purchasing power parity (PPP) adjusted output side and measured in 2017 U.S. dollars. Urban population is the share of total population residing in cities. Depreciation of capital is the value loss of the capital stock.

It is worth nothing that Austria's urbanization rate is relatively low compared to other high-income countries. Newcomb (1985) explain that this reflects the large availability of tourism related jobs in rural areas. Compared to the OECD average, Austria consumes more renewable energy. Overall Austria and its synthetic control unit a comparable across these dimensions.[12]

Table 2: Country weights in synthetic Austria

Country	Weight	Country	Weight	Country	Weight
Switzerland	0.194	Luxembourg	.111	Iceland	0.039
Ireland	0.345	Norway	0.311		

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

Table 2 shows the W vector of weights obtained for the synthetic control. The table shows that Austria is best reproduced by a combination of Switzerland, Ireland, Norway, Luxembourg and Iceland. The largest weight on Ireland (0.345) is not surprising, given the many social and economic similarities. Both countries have comparable sizes, life expectancy and infrastructures developments

[12] This small number of control can be used for this, although we also estimate a version with several other predictors inclusing government spending, quality of institutions, latitude, capital available per capita and human capital. This combination produces the smallest root-mean-square error. The results are also very similar if we consider different years than 1997, 1999 and 2001. All these results are available from the authors. For computation, we use the publicly available STATA routine written by Galiani and Quistorff (2017).

levels. Together, Ireland, Luxembourg, and Norway make up 85% of the synthetic Austria. Austria is best reproduced by this combination, and most other countries receive a weight of zero. This is an advantage of the SCM, as this choice among all OECD may be more arbitrary otherwise.

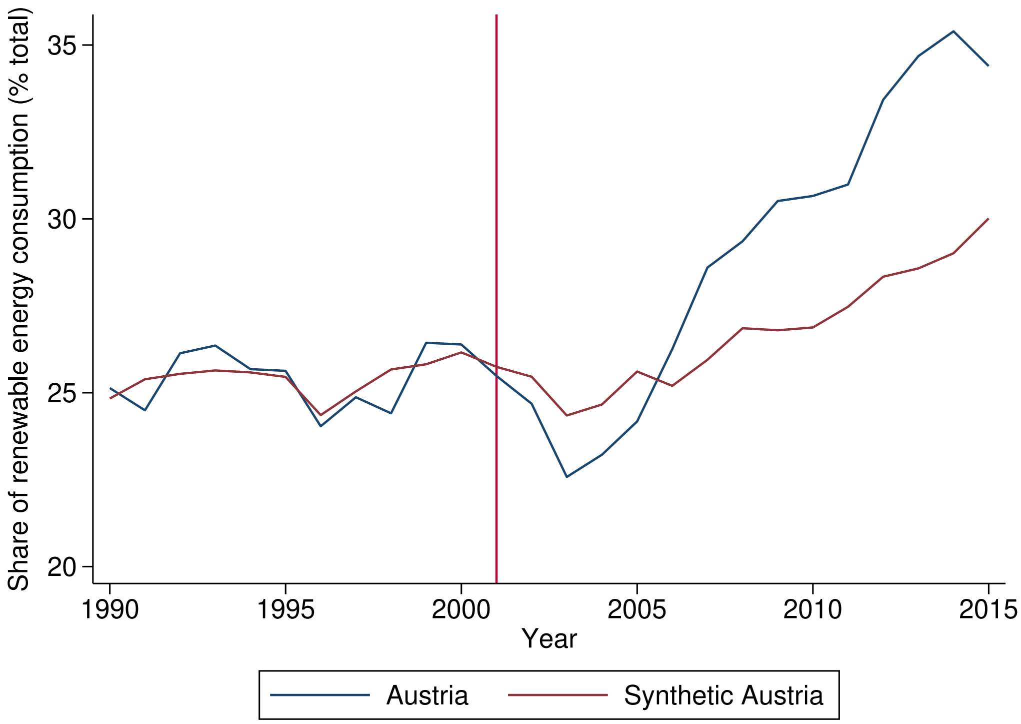

Figure 2: Share of renewable energy (% total primary energy consumption). There is a sizeable gap between Austria consumption of renewable energy and its synthetic control.

Looking Figure 2 we can make several observations. First, in the pretreatment period, the consumption of renewable energy in Austria is relatively high but stationary.[13] Secondly, even with the limited number of predictor variables, the synthetic control follows closely the Austrian trend before the policy enactment. Importantly, the posttreatment distance between Austria and the synthetic Austria measures the impact of the climate strategy of 2002. We note that the national consumption of renewable in Austria falls right after the policy and does not recover to the 2002 level until 2006. This initial dip is noteworthy. Based on placebo permutations (see Figure 8) this 1.76% initial percentage point decrease in renewable consumption is significant.[14]

[13] We formally test this hypothesis on pretreatment values. We perform a Dickey-Fuller unit root test (Paparoditis and Politis, 2018) on the Austria time series data. We reject the null hypothesis of the existence of a unit root at all common rejection levels in favor of the alternative hypothesis of stationarity.

[14] Storage capacity for non-renewable energy sources may explain this lagged response. Kilian (2008) documents that due to storage of oil in tanks, purchases may be delayed when the price of oil is high. In Austria's case, the law was passed in 2002, but accelerated residual oil reserves consumption may explain the initial negative effect. In an exergy

Figure 3 shows the gap more clearly for each year, and we note after 2005 that Austria's renewable consumption diverges from its synthetic control, culminating in a 6.38% increase in 2013 compared to its synthetic control.

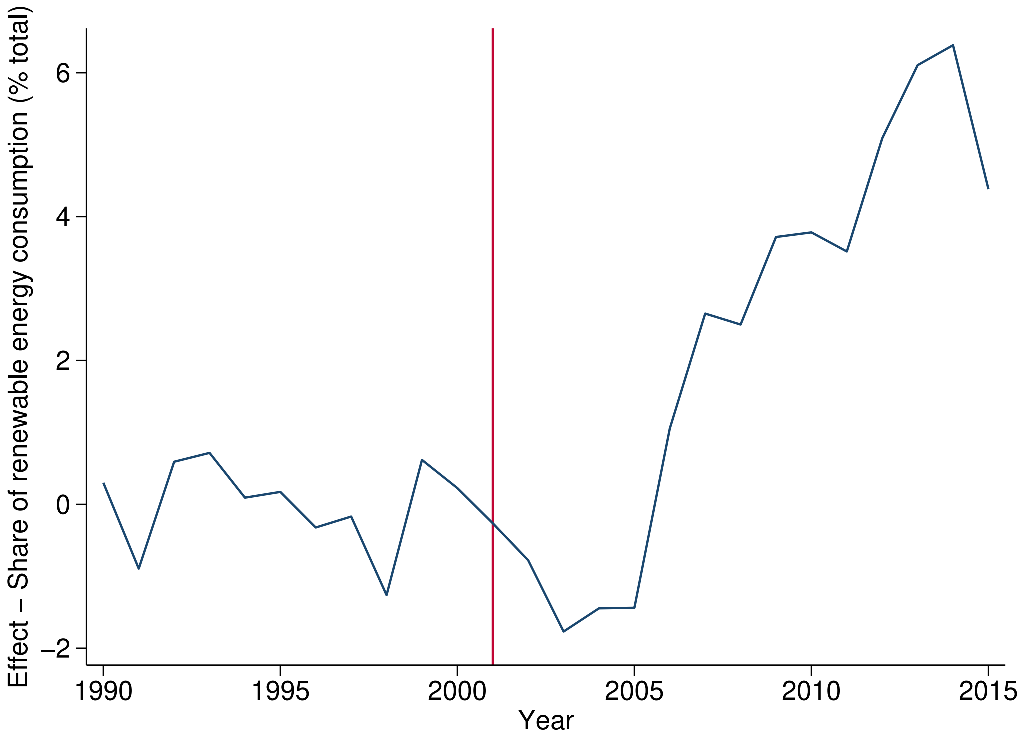

Figure 3: Difference in renewable energy consumption (% total final energy consumption) between Austria and the synthetic control. Before implementing the climate strategy, the difference is close to zero denoting an adequate match. After 2002, the effect is first negative but becomes strongly positive after 2005.

We estimate the average treatment effect across the 14 years following the policy to be an annual 2.41 percentage point increase in renewable energy consumption compared to other OECD countries. When these results are put into perspective with the original goals of the policy, Austria performed remarkably. The original law targeted the total renewable energy production. It had to first reach 80% then 85% of total electricity production. The latest World Bank data show that by 2014, 81.06% of Austria's electricity output originated from renewable sources. Since the mapping from electricity production to energy consumption is not 1:1 because of diversified energy sources and energy trade, the impact of the policy on consumption is not evident.[15] Our result show evidence that the Climate

analysis of Austria between 1900-2012, Eisenmenger et al. (2017) shows that energy inputs in the coal category decreased right after 2003 while the decline in the oil sector only occurs in 2005-2006 and persist after that. This also points to a delayed effect.

[15]Austria has been an importer of energy (especially from Germany) for several decades. However, with plans to

strategy of 2002 Austria did increase its domestic consumption of clean energy.

5.3 Robustness and sensitivity analysis

To assess the quality of the pre-period match we rely on the root mean square prediction error (RMSPE) in the pre-intervention period for goodness of fit. The RMSPE is given by:

$$RMSPE = \sqrt{\frac{1}{T_0}\sum_{t=1}^{T_0}\left(Y_{1t} - \sum_{n=2}^{N+1} w_n Y_{nt}\right)^2} \tag{2}$$

where Y_{1t} is the outcome in Austria at time t, T_0 is the time of intervention, w_n is the weight on country n and Y_{nt} is the outcome at the same time. If the pre-period match is adequate, the RMSPE ought to be minimal compared to the other placebos.[16] In cases when placebo estimates do not fit well in the pre-tax reform period, it is expected that they would not fit better after the intervention. We consider the ratio of the pre-period to the post-period RMSPE following Abadie et al. (2015). With a quality pre-period match and a subsequent divergence from the synthetic control, the treated unit can be expected to have a large ratio. Andersson (2019) interprets a large ratio as indicative of a true causal effect from the policy. The ratio is given by:

$$Ratio_n = \frac{RMSPE_{Post,n}}{RMSPE_{Pre,n}} = \frac{\sqrt{\frac{1}{T-(T_0+1)}\sum_{t=T_0+1}^{T_0}\left(Y_{1t} - \sum_{n=2}^{N+1} w_n Y_{nt}\right)^2}}{\sqrt{\frac{1}{T_0}\sum_{t=1}^{T_0}\left(Y_{1t} - \sum_{n=2}^{N+1} w_n Y_{nt}\right)^2}} \tag{3}$$

where w_n is the SCM generated weight for country n. T represents the number of time periods in the longitudinal data. In our case, this is 25 years because we begin in 1990 until 2014. T_0 is the time of intervention, which is 2002 in our case. We can obtain these ratios for all countries through placebo permutations.

decarbonized its economy by 2050, growth in solar, hydropower, wind and biomass sectors, it plans to increasingly export clean energy to the rest of Europe (see e.g. Witkop (2021)). The Renewable Expansion Act (EAG) was enacted on July 7th 2021 aiming to 100% of electricity supply to come from renewables and at least 32.5% of total energy to come from renewables by 2030.

[16] A placebo effect is estimated by calculating the impact of the policy on another country in the donor pool. Since the policy did not occur there, we expect any estimated effect to be the results of chance. In SCM context, this can be done for all other countries in the sample and Austria's output are expected to stand out because the policy did in fact happen there.

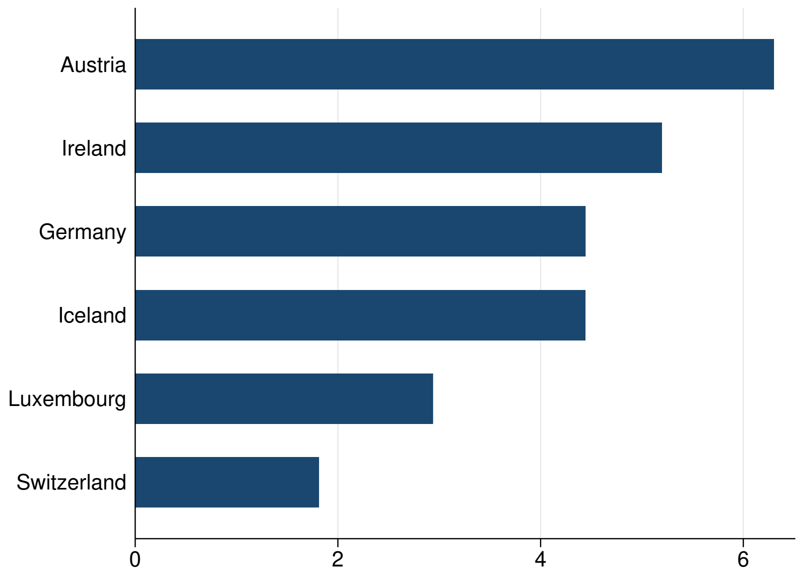

Figure 4: Ratio Test. Ratio of posttreatment RMSPE to pretreatment RMSPE for Austria and a few donors countries. We include the SCM donors and Austria neighbor countries.

Figure 4 shows that Austria has a large ratio compared to other countries in the sample.[17] If the treatment assignment were random, the chance of finding this ratio would be $1/28 = 0.035$ which is also the smallest p-value possible in this OECD sample size.[18]

Finally, we experiment with an alternate donor pool. Our choice of the OECD was motivated by comparability and data availability.[19] This choice, however represents a major comparison challenge. Although more than 150 countries signed the 1997 Kyoto protocol to lower the amount of greenhouse gases, OECD countries have been particularly keen on following through with the commitments. But this has not been the case everywhere (Erdogdu, 2010). Although the climate strategy was specific to Austria, several similar energy reforms happened all around Europe and the OECD around the same time, as shown by the upward trend of the OECD average in Figure 1. Practically, this means that one of the requirement of our SCM may not be fully met. This is a concern that is difficult important to address because it may imply that the policy impact has been underestimated due to comparison with countries that were behaving similarly.

[17] We obtain ratio for all countries, but only present a subset. We note that Italy and Japan obtained larger ratio than Austria. We address this point in the next sensitivity analysis.

[18] We also undertake a leave one out test following Andersson (2019). Given the large weight placed on Ireland, we remove it from the donor pool and estimate the policy impact. This is to ensure that our results are not driven by this country alone. We find similar results available from the authors upon request.

[19] Several countries are missing renewable consumption data prior 2000. This is not the case for OECD members among which WDI panel data starts back in 1990. Adding to this many OECD members are geographically near Austria in Europe, so the group was a viable choice.

To address this concern, we first enlarge the donor pool with other non-OECD countries, and then we remove OECD members who have had similar environmental policies as Austria (Grantham Institute). The alternative donor pool now has 130 countries, compared to 30 that we had before.[20]

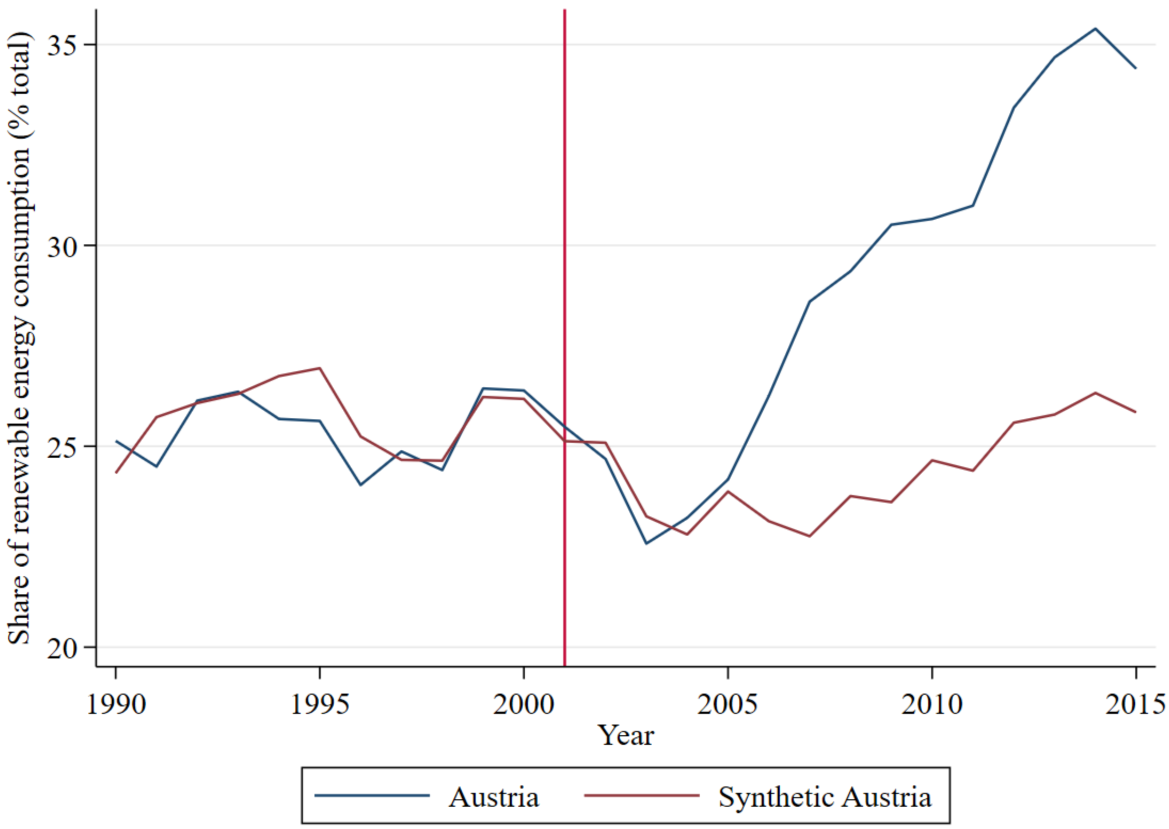

Figure 5: Austria and synthetic Austria in alternative donor pool. There is a larger gap between the two trends. Standardized p-values fall 6 years after policy enactment and show statistically significant increase in renewable energy consumption.

Figure 5 present the results in this alternative donor pool. The gap between Austria and the synthetic control is larger than the previous one. We no longer witness an initial fall in renewable consumption, but simply a null effect until 2005. There appears to be a response delay, as we observed before. It is not until 2006 that the two lines diverge. The standardized p-values also offer evidence that this growth is significant. In this alternative donor pool, the policy effect is estimated to be 4.86

[20]Based on similarly designed policy, we remove Netherlands, Israel, Italy, Japan, Belgium, Denmark, Switzerland, Ireland, Germany, Canada, Australia. Note that low-income countries as classified following Blankenau et al. (2007) are removed. We also experiment with other alternative donor pools based on geography or previous renewable consumption levels. Although countries like Italy and Japan have had an upward trend in renewable consumption, like Austria they may not be entirely comparable. Austria's growth started from an already high level, as shown in Figure (1). While experimenting with different pools, we find similar results.

annual percentage point increase in renewable energy consumption. One of the insight from these results is that the influence of climate policy is a medium to long term one.

6 Did more renewable energy consumption hurt Austria's GDP?

As we commence with this section, another important question is whether such a large policy shift has had a negative effect on the Austrian economy. Addressing the climate crisis involves a cost-benefit analysis because of the dependence of industrial economies on energy in general. Although the long-term benefits are evident, a shift away from fossil fuels has short-term trade-offs.[21] Due to creative destruction, new jobs will be emerge, but others jobs will ineluctably disappear, even if the shift is likely to have an overall positive result. Alexander (2022) discusses the example of the US. The shift from fossil fuels means more electric vehicles, electric and geothermal heat pumps and more electricity in industrial manufacturing. This is estimated to cost $320 billion annual from 2020 until 2050. To put this into perspective, the investment represents about 8% of the annual US federal budget. The report estimates that this may save $700 billion a year by 2040 and create about 1 million additional jobs during the 30-year transition.

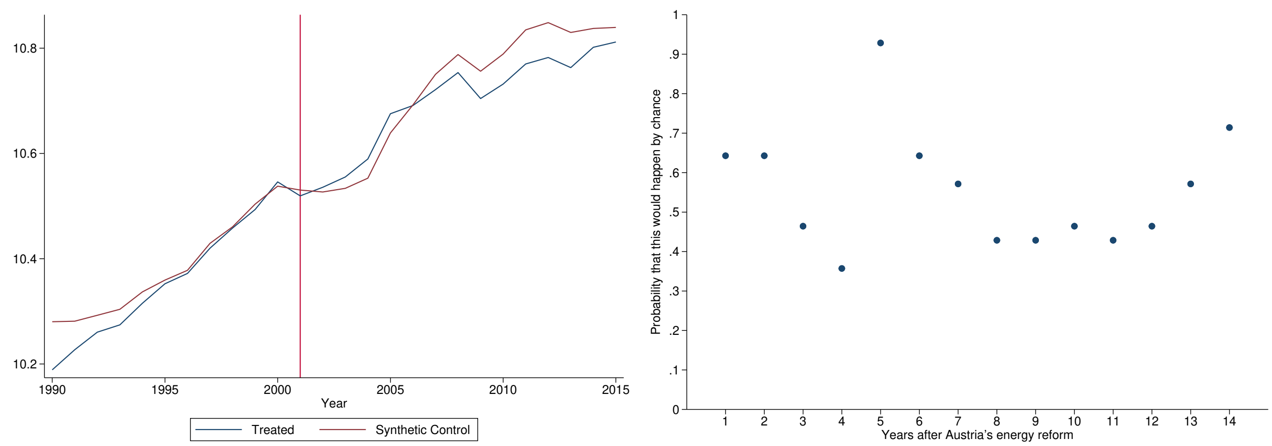

Figure 6: Austria and synthetic Austria per capita GDP. There is no significant gap between the two trends. Standardized p-values are never close to common significance levels.

[21]Among BRIC countries (Brazil, Russia, India and China), Venkatraja (2020) uses panel data between 1990-2015 to estimate the impact of renewable energy consumption on growth. Results shows that among these countries, higher renewable energy consumption is associated with lower economic growth. In contrast, Kuosmanen et al. (2020) study actual abatement cost per capita result from the Kyoto Protocol, focusing on OECD countries between 1990 and 2015. Results show that the cost in per capita terms has been lower than original forecasts. The authors interpret this as an encouragement for more extensive climate mitigation policy.

Other research provides evidence that renewable energy consumption has a definite positive impact on economic output. Inglesi-Lotz (2016) investigates the impact of renewable energy consumption on welfare, environment quality and economic conditions. Results show that this impact is positive. Wang and Wang (2020) focuses on a panel of OECD countries using a non-linear approach. Specifically, the study employs panel threshold regression models. The results show that more renewable energy consumption has a positive effect on growth and that this effect changes as the threshold varies offering evidence of a non-linear relationship. In this section, we explore whether Austria's climate strategy had a negative impact on the countries per capita GDP. Figure 6 shows the evolution of per capita income between Austria and its synthetic control. In the post-treatment period, the two lines closely follow each other. After 2006, Austria's per capita income is slightly lower than the synthetic unit, but this effect is never significant as shown by the high standardized p-values. We interpret these results as evidence against the hypothesis that the adoption of renewable energy had a negative effect on Austria per capita income.

7 Conclusion and policy implications

As our study illustrates, the implementation of dedicated and focused policies can lead to significantly positive impacts on the natural environment, including the mitigation of climate change. For the case of Austria, the implementation of their climate strategy marked the start of a new growth trend in renewable energy consumption in the country, post-2002 to 2015. Specifically, Austria's climate strategy showcased the transitioning from the use of polluting fossil fuels to clean renewable energy sources (e.g., solar, wind, etc.) as one of the leading strategies to combat climate change. Noteworthy to mention, in this scenario renewable energy was integrated into multiple and various key sectors, thus potentially providing a roadmap for other countries seeking similar carbon emission cuts and/or for communities seeking to adapt and build resilience to the impacts of climate change. The results also depicted a notable increase in its domestic consumption of clean energy, with a sizeable gap recorded between Austria's consumption of renewable energy and its synthetic control after the year 2005. This effect is further strengthened by the larger ratio obtained for the country within the sample size of the selected countries of the OECD region, and confirmed by the simulation of the results with an alternative sample of countries, which highlights an even more significant growth in renewable energy consumption. Another key finding of the results is the timeframe of the policy impact. Here, results highlight that the timeframe for the effectiveness of the policy was rather in the medium to long-term versus short-term. Hence, at a time when emerging energy security and geopolitical issues are driving some European states to compromise on their decarbonization ambitions, this study's findings not only suggest, but rather encourage that bold climate policy and actions (with a focus on renewable energy promotion) be sustained, over the long-run.

Furthermore, or perhaps, sustaining such actions could support OECD/European countries to scale up renewable energy use (at least in the medium- to long-term) and wean themselves off imported fossil fuels.; in turn helping reduce their susceptibility to external energy prices, supply shocks, and improving energy security.

Finally, the implementation of Austria's climate strategy positively impacted per capita income as compared to the original forecast, thus highlighting the economic benefits of such a strategy. And though statistical significance was not garnered on the GDP front, one could infer that per capita GDP was positively impacted, too. Taken together, our study affirms that climate action that focuses on renewable energy promotion may be compatible with economic development and that, perhaps, climate protection does not have to be at the expense of economic growth. As such, at a time when the global economy is facing an economic downturn, governments may want to consider injecting, or at the very least sustaining investments in climate action, particularly renewable energy deployment.

In closing, it should be noted that while the present study demonstrates that the implementation of the climate strategy in the 2000s was the anchor point of the renewable energy consumption trend observed in Austria, it should be acknowledged that this would have not been possible without the subsequent deployment of different energy specific policies, regulations, and instruments that provided additional momentum. Therefore, while a climate strategy may provide a broad frame and set out strategic goals of a country's climate agenda, subsequent sector specific regulations that spell out clear actions and responsibilities are necessary for the realization of these goals. This point would seem congruent with the literature, too, as Adelaja et al. (2010) highlights that there is a direct correlation between the existence of renewable policies portfolio in a given space and the structure of the renewable energy market influencing the outcomes of the industry in the sector. Indeed, Austria's robust policy in the promotion of renewable energy consumption can inspire and potentially act as a roadmap to other European countries as they shift dependency on fossil fuels. Now more than ever, this is particularly important amidst the ongoing energy crisis that the European continent is facing as a consequence of the Russia-Ukraine conflict.

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8 Appendix

8.1 List of OECD countries

This is the list of countries used in the original donor pool:

- **OECD members**: Austria, Australia, Belgium, Canada, Chile, Colombia, Costa Rica, Denmark, Finland, France, Germany, United Kingdom, Greece, Iceland, Ireland, Israel, Italy, Japan, Hungary, Luxembourg, Mexico, Netherlands, Norway, New Zealand, Portugal, Spain, Sweden, Switzerland, Turkey, United States.

8.2 The synthetic control method

This section provides additional insights into the SCM. We observe $J+1$ countries, and only Austria is exposed to the reform. Based on the matching literature, we refer to all potential controls as the "donor pool". In our paper, the donor pool is made up of 30 countries at first. We also assume that Austria is uninterruptedly affected by the reform after the 2012. Let Y_{nt}^N be the renewable share of primary energy consumption in country i at time t in the absence of any intervention with $n = 1, ..., J+1$, and time periods $t = 1, ..., T$. Let T_0 be the number of pre-reform years, with $1 \leq T_0 < T$. Let Y_{nt}^I be the outcome observed for Austria at time t, assuming that country i is exposed to the intervention in period $T_0 + 1$ to T. Our assumption is that the 2002 Climate strategy had no effect on the outcome of interest before the implementation. However, Abadie et al. (2010) note that in practice, the impact of the policy change could be felt earlier than the legal enforcement date. In such cases, they advise reconsidering T_0 to have it be the first period in which the outcome can possibly be affected.

This also implies no interference between countries (Rosenbaum (2007)). Let now $\alpha_{nt} = Y_{nt}^I - Y_{nt}^N$ be the effect of the Austria energy 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 Austria and zero otherwise. The observed outcome for the country i at time t is:

$$Y_{nt} = Y_{nt}^N + \alpha_{it} D_{it}.$$

We consider Austria as country 1. It is the only one exposed to the tax cuts, and only after period T_0 (with $1 \leq T_0 \leq T$), we have that:

$$D_{nt} = \begin{cases} 1 & \text{if } n = 1 \text{ and } t > T_0 \\ 0 & \text{otherwise.} \end{cases}$$

We target the estimation of $(\alpha_{1T_{0+1}}, ..., \alpha_{1T})$. For t $> T_0$,

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

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 post reform impact is given by the difference between the observed and the counterfactual value for Austria. The dynamic treatment effect is thus:

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

where $j = 1$ is Austria and $j \in \{2, ..., J+1\}$ are the donor pool countries, and T_0 is the number of pre-intervention quarters. The average treatment effect (ATE) is given by:

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

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

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

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, state level transitory shocks. When $\lambda_t = 1$ and $\mu_j = \delta_j$, the model is simplified to a two-way fixed effects model.

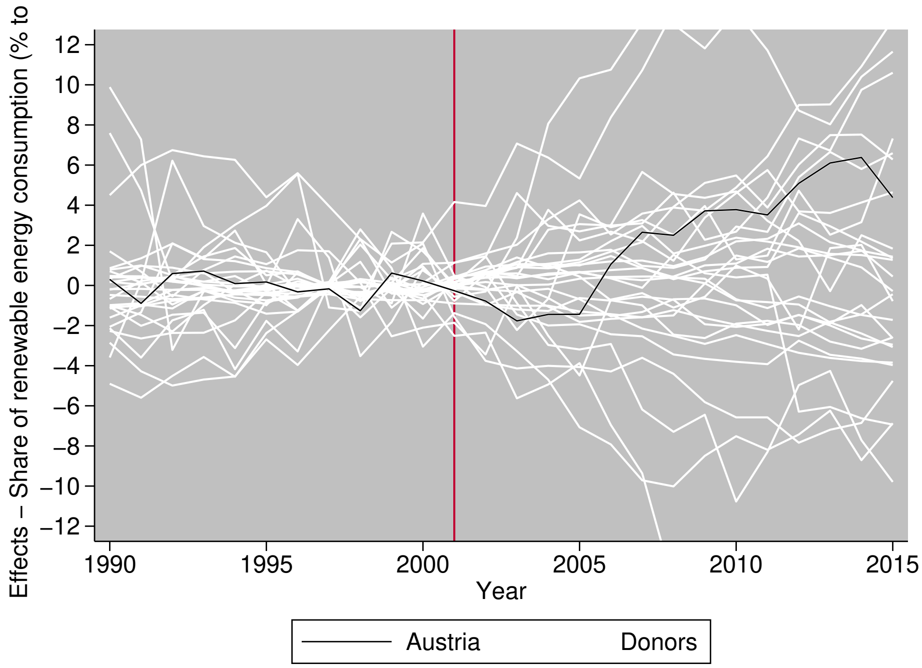

Figure 7: Placebos synthetic controls compared to Austria. The increase in the share of renewable consumption in Austria compared to placebos of donor countries. Following the Climate strategy of Austria, the evolution of the outcome variable is significantly positive.

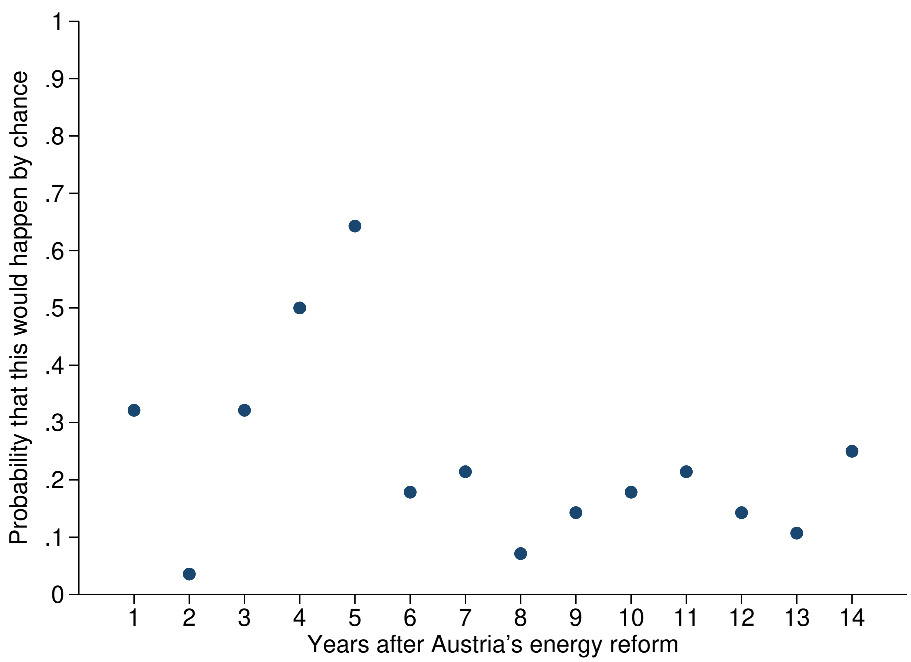

Figure 8: Standardized p-values of effects. The proportion of placebos standardized effects which are at least as great as Austria is well under 1% for most years following the intervention. This offer evidence against the possibility that the estimated effect has happened by chance.