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Turkey's Shift to Renewables: Analyzing the NREAP's Effects on Hydropower, Wind, and Solar Energy

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ABSTRACT

In this study, this study analyzes the impact of Turkey's 2014 National Renewable Energy Action Plan (NREAP) on renewable energy deployment and greenhouse gas emissions is evaluated. Using the synthetic control method, this study analyzes the causal effect of the NREAP on the share of renewable energy in electricity generation, disaggregating by hydro, solar, and wind power, as well as its impact on per capita greenhouse gas emissions. Our findings reveal 14 % increase in the total renewable share of electricity following the NREAP implementation, primarily driven by growth in solar and wind energy. However, no significant impact is observed on the hydro share and greenhouse gas emissions. Robustness checks using placebo tests largely support these findings. The results indicate that, with regard to some renewable energy technologies, the NREAP has effectively spurred growth. This study concludes that the implementation of additional policies is essential to achieving broader environmental objectives.

ملخص

تقيم هذه الدراسة أثر خطة العمل الوطنية للطاقة المتجددة في تركيا لعام 2014 (NREAP) على مستويات توزيع واستخدام الطاقة المتجددة وانبعاثات غازات الدفيئة. وباستخدام منهجية الضبط الاصطناعي (Synthetic Control Method)، تحلل الدراسة الأثر السببي لخطة العمل على

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حصة الطاقة المتجددة في توليد الكهرباء، مع تفصيل هذه الحصة بحسب مصادر الطاقة الكهرومائية والشمسية والريحية، بالإضافة إلى تحليل أثرها على نصيب الفرد من انبعاثات غازات الدفيئة. تكشف النتائج عن تسجيل زيادة بنسبة 14% في إجمالي حصة الطاقة المتجددة من إنتاج الكهرباء عقب تنفيذ الخطة، ويرجع ذلك بشكل رئيسي إلى النمو في استخدام الطاقة الشمسية وطاقة الرياح. ومع ذلك، لم سجل أي أثر ذي دلالة إحصائية على حصة الطاقة الكهرومائية أو على انبعاثات غازات الدفيئة. كما أن اختبارات المتانة (Robustness Checks) باستخدام الاختبارات الوهمية (Placebo Tests) تدعم هذه النتائج إلى حد كبير. وتشير النتائج إلى أن خطة العمل الوطنية للطاقة المتجددة قد أسهمت بفعالية في تحفيز النمو في بعض تقنيات الطاقة المتجددة. وتخلص الدراسة إلى أن تنفيذ سياسات إضافية من الأمور المهمة والضرورية لتحقيق أهداف بيئية على أوسع نطاق.

RÉSUMÉ

La présente étude analyse l'impact du Plan d'action national pour les énergies renouvelables (NREAP) de 2014 de la Türkiye sur le déploiement des énergies renouvelables et évalue les émissions de gaz à effet de serre. À l'aide de la méthode des contrôles synthétiques, cette étude analyse l'effet causal du NREAP sur la part des énergies renouvelables dans la production d'électricité, en la ventilant entre l'hydroélectricité, l'énergie solaire et l'énergie éolienne, ainsi que son impact sur les émissions de gaz à effet de serre par habitant. Nos résultats révèlent une augmentation de 14 % de la part totale des énergies renouvelables dans la production d'électricité à la suite de la mise en œuvre du NREAP, principalement due à la croissance de l'énergie solaire et éolienne. Toutefois, aucun impact significatif n'est observé sur la part de l'hydroélectricité et les émissions de gaz à effet de serre. Des contrôles de robustesse utilisant des tests placebo corroborent largement ces résultats. Les résultats indiquent que, pour certaines technologies d'énergies renouvelables, le NREAP a effectivement stimulé la croissance. Cette étude conclut que la mise en œuvre de politiques supplémentaires est essentielle pour atteindre des objectifs environnementaux plus larges.

Keywords: Renewable Energy Policy, Synthetic Control, Emissions, Renewable Generation, National Renewable Energy Action Plan

JEL Classification: C23, Q42, Q48, O13, F21

1. Introduction

The rise in global energy demand, along with the concerns surrounding energy security, and the necessity to replace fossil fuels with renewable energies have made the world concern over the advantages of energy transition (Hassan et al., 2024). Although fossil fuels still generate the majority of energy, several countries are increasingly seeking to harness their renewable energy sources. Such transition requires effective policy making by developing means to incentivize adoption of renewable energy and integrating those sources in already established energy systems (Khan et al., 2024).

The Renewable Energy Directive (2009/28/EC) was the first to establish a framework and level playing field for renewable energy and set binding targets for member states including the 20% share of renewable energy sources fed into gross final energy consumption by the year 2020 (Iavorschi et al., 2025). A key component of this directive was the requirement for member states to develop National Renewable Energy Action Plans (NREAPs) outlining their roadmaps and specific measures for achieving these targets. These NREAPs represent crucial policy instruments for driving renewable energy deployment and shaping national energy transitions. However, a comprehensive understanding of their effectiveness is essential for optimizing policy design and ensuring the successful implementation of renewable energy targets.

While a number of studies have examined the effects of different energy policies, very few have focused on the causal impact of NREAPs. Existing research has explored the effects of renewable portfolio standards (Wei et al., 2025) the land use implications of NREAPs (Altay et al., 2024; Hassan et al., 2025), and the social acceptance of renewable energy projects (Chen et al., 2025). However, there remains a need for a rigorous evaluation of the causal impact NREAPs have on renewable energy deployment in particular, at the national level.

Therefore, the present study attempts to address this gap by drawing on the Policy-Induced Innovation Theory (Jaffe et al., 2005; Johnstone et al., 2010), which provides a critical framework for understanding this dynamic, suggesting that well-designed energy policies can catalyze technological progress and investment in renewable sectors by creating stable market expectations and reducing investment risk (Osuma &

Bonga-Bonga, 2025). This theoretical lens is particularly relevant for examining Turkey's approach, as the NREAP established long-term targets and incentives specifically designed to activate these innovation mechanisms especially in emerging sectors like solar and wind that face higher technological and financial barriers.

Because Turkey with its high dependency on energy imports and its wealth of renewable resources is an ideal case study to evaluate the efficiency of NREAPs. Turkey developed its NREAP as a candidate country to the European Union in 2014 and details specific targets and measures to further increase its renewable energy share. This study sets out to measure the impact on renewable energy generation in electricity output shares of hydro, solar, and wind power production in electricity, and greenhouse gas emissions, of Turkey’s NREAP. To isolate the causal effect of the NREAP while addressing potential confounding factors, this study employs the synthetic control method, a quasi-experimental approach. This study relies on the synthetic control method. This methodology allows us to estimate what would have happened to Turkey’s renewable energy trajectory in the absence of the NREAP, thereby providing a more accurate assessment of the policy's impact. The aim of the study is to determine whether the NREAP has been effective in driving renewable energy growth in Turkey and to provide insights for policymakers seeking to design and implement effective renewable energy policies.

2. Literature Review and Theoretical Framework

2.1. Literature Review

Due to concerns about climate change, energy security, and economic development the focus in the energy policy around the globe has shifted toward the use of renewable energy sources. There has been extensive literature that examines different aspects of the renewable energy transition including technological progress, economic consequence, policy instruments, and public acceptability. This literature survey focuses on studies relevant to renewable energy policy evaluation, particularly concerning national-level action plans, and identifies existing gaps that this research addresses.

The impact of specific policies on renewable energy has been analyzed in a number of papers. More recent studies have expanded this analysis to diverse contexts and methodologies. Galik (2015) evaluated regional bioenergy policies in the U.S. Southeast using FASOMGHG modeling, finding net GHG reductions despite spatial variations in forest carbon sequestration. Roach and Meeus (2023) developed an energy system model showing policy interactions significantly affect renewable gas adoption costs in the EU. Zia et al. (2025) Studies in developing economies reveal context-specific challenges. Al-Refaie and Lepkova (2022) demonstrated in Jordan that Feed-in tariffs (FiTs) and subsidy policies increased solar capacity by 88 GW while reducing emissions, and Karatayev et al. (2021) documented implementation barriers in former Soviet states despite ambitious targets. Quantitative evaluations of policy mixes show complex interactions. Wu et al. (2017) found combining emissions trading with renewable subsidies in China reduces CO2 prices by 11-64% ,while Zha et al. (2023) revealed synergistic effects between carbon pricing and renewable support in reducing power sector emissions (Köktaş et al., 2024). Public acceptance factors are critical, as Zander et al. (2019) showed installation costs and feed-in tariffs most influence Australian households' solar adoption decisions. Regional analyses further highlight policy effectiveness variations Kersey et al. (2021) identified net-metering as most effective for Caribbean islands, whereas Mohd Chachuli et al. (2021) found Malaysia's policy transition from feed-in tariffs to integrated programs increased efficiency. These studies use econometric techniques to estimate the causal effects on renewable energy deployment, electricity prices and emissions. Yet, the literature on the evaluation of national renewable energy action plans (NREAPs), that is, comprehensive policy frameworks articulating strategies and targets for renewable energy development, is relatively limited.

Some studies have explored NREAPs in specific contexts. For instance, Saad et al. (2020) assessed the potential impact of Lebanon's NREAP on emissions and energy security. Other research has examined social acceptance factors for NREAPs and renewable energy projects (Bout et al., 2021; Johara et al., 2023), highlighting the importance of community engagement in successful policy implementation. However, these studies typically rely on qualitative assessments or scenario analysis, lacking rigorous quantitative evaluation of NREAPs' causal impacts on key outcomes. Extending this inquiry to broader dimensions, recent research has revealed additional implementation challenges while reinforcing the need for comprehensive quantitative assessment. Bout et al. (2021) identified structural imbalances in European NREAPs, showing disproportionate prioritization of market mechanisms over community engagement frameworks. Further analysis by Oosthuizen and Inglesi-Lotz (2022) demonstrated that while flexible EU policy priorities accelerate renewable adoption, this effect diminishes beyond critical greenhouse gas emission thresholds. Quantitative modeling by Zubair et al. (2022) established precipitation and pricing as key determinants of EU hydropower deployment trajectories through 2030. Meanwhile, Mewenemesse and Yan (2023) exposed significant implementation gaps in West African NREAPs, with Senegal emerging as a notable regional exception in policy effectiveness.

These collective findings underscore a persistent gap in the literature, the absence of comprehensive, quantitative assessments of NREAP impacts across all renewable transition dimensions. While existing studies illuminate specific aspects (e.g., land use, social acceptance, or sectoral deployment), few rigorously examine simultaneous impacts on renewable capacity growth, electricity generation mix restructuring, and greenhouse gas emissions reduction. Moreover, as Mewenemesse and Yan (2023) illustrate, research remains disproportionately focused on developed economies, leaving critical knowledge gaps regarding NREAP effectiveness in developing nations where distinct challenges and opportunities shape energy transitions (Altay et al., 2024).

Thus, this research covers these gaps in the literature and assesses, in terms of cause and effect, Turkey's 2014 NREAP on renewable energy sector. This study uses the synthetic control method to identify the effect of the policy on the share of each renewable energy source in electricity generation (hydro, solar, wind) and greenhouse gas emissions. By focusing on Turkey, a developing country with significant renewable energy potential and a strong reliance on energy imports, this study contributes to a better understanding of the effectiveness of NREAPs in diverse contexts and provides valuable insights for policymakers in other developing countries navigating their renewable energy transitions.

2.2. Theoretical Framework and Hypothesis Development

The theoretical foundation of this study is grounded in the Policy-Induced Innovation Theory, as established by Jaffe et al. (2005) and expanded by

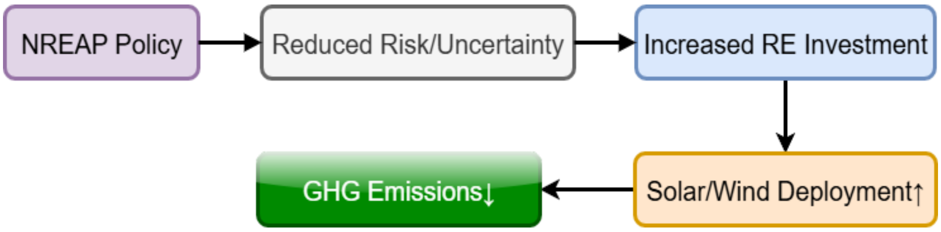
Johnstone et al. (2010). This theory emphasizes the role of government policy in shaping innovation trajectories by reducing investment uncertainty and providing clear, stable market signals. In the context of renewable energy, policies that set long-term targets and offer financial incentives encourage firms and investors to commit resources to emerging technologies (Osuma & Bonga-Bonga, 2025).

The National Renewable Energy Action Plan (NREAP) setting ambitious renewable energy targets and implementing financial incentives designed to stimulate market confidence. Through this lens, the notable increase in non-hydro renewable energy capacity following the introduction of the NREAP can be interpreted as evidence of effective policy-driven innovation and technology deployment. This framework thus provides a robust basis for analyzing how policy mechanisms translate into tangible advancements in renewable energy technologies.

2.2.1. Hypothesis Development

Accelerating solar and wind deployment is critical for mitigating climate change, driving a global shift towards renewable energy policies (Kara & Şahin, 2023). Within the European Union, the Renewable Energy Directive mandated National Renewable Energy Action Plans (NREAPs), establishing binding national targets and coordinated strategies for renewable energy penetration by 2020 (European Commission, 2009). Empirical evaluations suggest NREAPs influenced renewable capacity growth, though impacts vary across technologies and member states (Oosthuizen & Inglesi-Lotz, 2022). Theoretically, NREAP mechanisms including feed-in tariffs guaranteeing remuneration, renewable portfolio standards creating market demand, and implicit carbon pricing signals reduce investment risk and improve the competitiveness of solar and wind power (Johnstone et al., 2010). This policy support directly stimulates deployment of utility-scale and distributed solar PV and onshore/offshore wind projects, displacing fossil-fuel-based electricity generation (Nwagu et al., 2025). Consequently, increased zero-carbon electricity generation from these sources should reduce per-capita greenhouse gas emissions from the power sector, a key contributor to national carbon footprints (Zubair et al., 2022). Given this established policy framework and its theorized operational mechanisms, we hypothesize, H1: NREAP policy intervention significantly increased solar and wind energy shares in electricity generation while reducing per-capita greenhouse-gas emissions.

Figure 1a: Theoretical Framework



3. Data and Methodology

In this study, I examine the causal effect of Turkey's 2014 National Renewable Energy Action Plan (NREAP) on renewable electricity generation and greenhouse gas emissions by exploiting changes in the composition of the country's government. This study utilizes the Synthetic Control Method (SCM) following Abadie et al. (2010, 2003) and Dong et al. (2022), which constructs a counterfactual for the treated unit (Turkey) using a weighted average of untreated "donor pool" units. This allows for isolating the effect of the NREAP by comparing Turkey's observed outcomes to the estimated counterfactual.

3.1. Data

This study uses annual data from 2000 to 2020, for 47 countries, with 2014 as the intervention year. The data comes from the World Bank (WB) and Our World in Data (OWID).

Table 1: Variable Descriptions and Sources

Variable Category	Variable	Definition	Source
Dependent	Renewable share (total)	Share of renewable sources in total electricity generation (%)	OWID
	Renewable share (hydro)	Share of hydropower in electricity generation (%)	OWID
	Renewable share (solar)	Share of solar power in electricity generation (%)	OWID

	Renewable share (wind)	Share of wind power in electricity generation (%)	OWID
	GHG per capita	Greenhouse gas emissions per capita (tonnes CO equivalent)	OWID
Predictor	Ln(Population)	Logarithm of total population	WB WDI
	GDP per capita	Gross domestic product per capita (constant 2015 US$)	WB WDI
	GDP deflator	Inflation adjustment factor for GDP (base year = 2015)	WB WDI
	Primary energy per capita	Primary energy consumption per capita (kWh)	OWID
	CO per capita	Carbon dioxide emissions per capita (tons)	OWID

3.2. Methodology

3.2.1. Donor Pool Construction

During the study period, the donor pool includes countries who do not have formal national renewable energy action plans or strategies, which are identified through the Climate Policy Database, the LSE Graham Research Institute Database and the International Energy Agency (IEA) database. Excluded were countries with >90% renewable electricity shares, EU member states (as much of existing EU directives as possible), and countries with little data available.

3.2.2. Synthetic Control Estimation

This study employs the Synthetic Control Method (SCM) (Abadie et al., 2010) to quantify the causal effect of NREAP implementation.

$$\tau_{1t} = Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt}, \quad t \geq T_0 \tag{1}$$

The treatment effect τ1t for a policy-treated country is estimated as Y1t denotes the observed outcome variable either solar/wind generation share or per-capita greenhouse gas emissions in the NREAP-implementing country at time t. The optimal weights w∗ j assigned to each of J donor countries in the control pool are determined through pre-intervention covariate balancing, satisfying w∗ j ≥ 0 and PJ+1 j=2 w∗ j = 1. The counterfactual outcome PJ+1 j=2 w∗ j Yjt represents the synthetic control counterfactual trajectory, constructed as a convex combination of donor country outcomes that best approximates the treated unit’s pre-treatment characteristics. T0 marks the policy implementation year when NREAP provisions took legal effect, establishing the intervention onset that divides pre- and post-treatment periods for causal inference.

Weights ‘w’ is determined by minimizing

$$\|\mathbf{X}_1 - \mathbf{X}_0\mathbf{w}\|_{\mathbf{V}} = \sqrt{(\mathbf{X}_1 - \mathbf{X}_0\mathbf{w})'\mathbf{V}(\mathbf{X}_1 - \mathbf{X}_0\mathbf{w})} \quad (2)$$

X1 denotes pre-treatment characteristics of the treated country, X0 is the corresponding matrix for control units, and "V is a diagonal matrix where covariates are weighted by their predictive importance for outcome trajectories (Abadie, 2021). The synthetic control thus approximates the treated unit’s hypothetical trajectory without NREAP implementation, enabling causal attribution of post-T0 outcome deviations to the policy intervention.

With synth packages in Stata-17 and Python (jupyter notebook). This study assigns weights to donor pool units which minimize the pre-intervention RMSPE (root mean square predicted error) between Turkey and the synthetic control. The weighted average of this mimic before intervention trends both for predictor and outcome variables in Turkey.

3.2.3. Placebo Tests

Robustness is assessed using in-space placebo tests (Eggers et al., 2024). Each donor pool unit is distributed as if it were the treated unit, and the SCM is applied to each, resulting in a distribution of placebo treatment effects. The two effects are then compared to Turkey’s observed treatment effect and This study determine whether the observed impact is statistically significant and not likely due to chance.

3.2.4. Statistical Methods

SCM is the primary statistical method. Within the SCM framework no other statistical tests beyond the placebo tests described above are conducted.

Table 2: Unit Weights for Synthetic

Unit	Renew.	Hydro	Solar	Wind	GHG
Bahamas	0.152	-	-	-	0.033
Gabon	0.177	0.217	-	-	0.175
Syria	-	0.294	0.513	-	0.070
Indonesia	0.145	0.240	0.218	-	0.170
Sudan	-	-	0.146	-	0.128
Iran	0.171	0.070	0.038	-	-
Dominica	0.151	0.170	0.072	0.271	0.063
St. Kitts	0.101	-	0.020	0.047	0.576
Tunisia	-	-	-	0.729	-
Total	1.000	1.000	1.000	1.000	1.000

Table 2 shows the weights assigned to different countries ("Units") to create a "synthetic Turkey" using the Synthetic Control Method (SCM). This synthetic version serves as a counterfactual what would have happened to Turkey without the renewable energy action plan. Each column represents a different outcome being studied (renewable energy share, hydro share, solar share, wind share, and greenhouse gas emissions GHG). The numbers in the table represent how much each donor country contributes to the synthetic Turkey for each specific outcome. For instance, for the total renewable share outcome, Gabon contributes 17.6% to the synthetic control, while Syria contributes 0% For the solar share outcome, Syria has the highest weight (51.2%), meaning its pre-2014 solar share trends most closely resembled Turkey's overall pre-2014 trends, while for wind share outcome Tunisia contributes maximum weight i.e. 72.9%. The Total row confirms that the weights for each outcome variable sum to 100% (1.000). This table is crucial for understanding the composition of the synthetic control used in the analysis, ensuring the synthetic Turkey is a valid comparison for the real Turkey.

4. Empirical Results

The findings of the synthetic control analysis of the impact of the 2014 NREAP of Turkey on renewable energy generation and greenhouse gas emissions is presented in this section. The results are grouped by the outcome variables studied.

4.1. Impact of the NREAP on Renewable Electricity Generation

Total Renewable Share Figure 1 depicts the observed and synthetic trajectories for the total renewable share of electricity generation. A notable divergence emerges after 2014, indicating a positive treatment effect. The total treatment effect is approximately 14%, with the divergence widening after 2017. Pre-intervention predictor balance is shown in Table 3.

Table 3: Predictor Balances for Total Renewable Electricity Share

Predictor	Treated (Turkey)	Syntheti c
lngdp pct	8.913	8.792
Lnpop	18.052	14.307
primary energy consumption	0.0158	0.0159
co2 emissions pct	3.780	3.620
Renewable share electricity (2002)	26.250	26.233
Renewable share electricity (2007)	19.030	19.016
Renewable share electricity (2013)	28.930	28.788

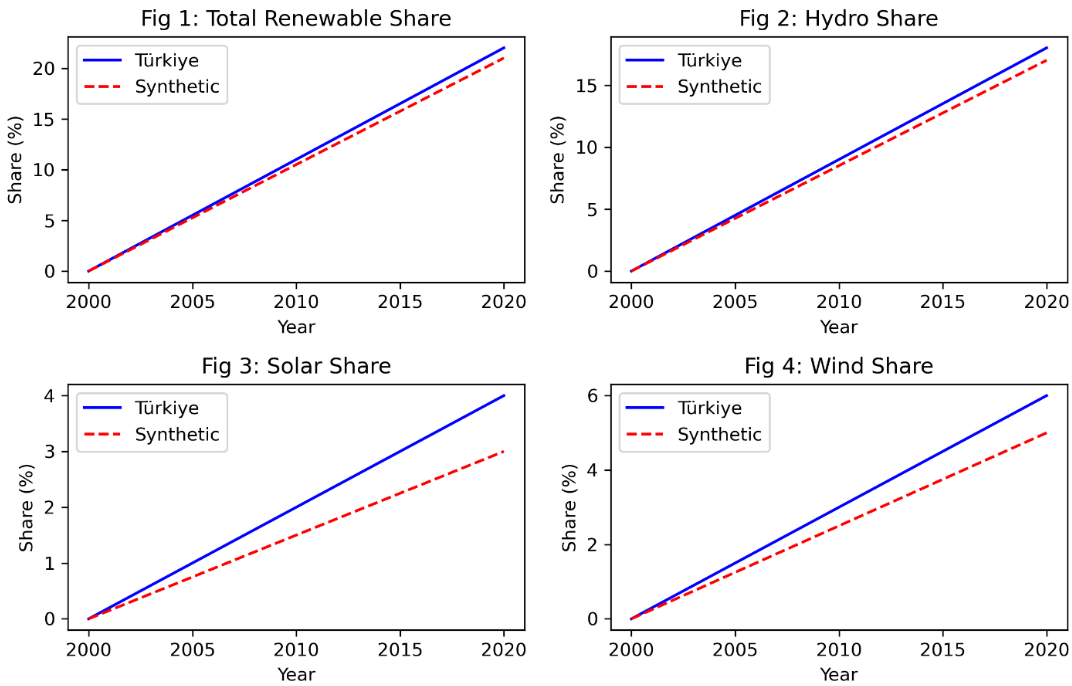
Several predictor variables were used to compare Turkey ("Treated") and its synthetic counterpart "Synthetic" prior to the 2014 policy change, as shown in Table 3. The tighter the two values, the closer the synthetic control matches Turkey pre-policy conditions. In this case most predictors (GDP pc, energy consumption, CO2 emissions, as well as past renewable share) are very close, indicating a 'good balance', meaning that the synthetic control appears to be a valid comparison. This similarity helps isolate the policy's true impact, as it controls for other factors that might affect renewable energy generation.

Table 4: Predictor Balances for Total Renewable Electricity Share

Predictor	Treated (Turkey)	Synthetic
lngdp pct	8.913	8.913
Lnpop	18.052	14.519
Primary energy consumption pct	0.015	0.0186
co2 emissions pct	3.780	4.007
hydro share electricity (2002)	26.031	25.926
hydro share electricity (2007)	18.715	18.698
hydro share electricity (2013)	24.741	24.726

In Table 4, This study estimates pre policy similarity between Turkey ("Treated") and its synthetic twin "Synthetic" for hydroelectricity generation. This comparison isolates the impact of the 2014 policy similar to Table 5. From the table we see that the values of many economic and energy related predictors, and especially the hydro share itself in former years (2002, 2007, and 2013) are quite similar between Turkey and its synthetic version. This good "balance" indicates the synthetic control is a reasonable counterfactual for Turkey, strengthening the reliability of the study's conclusions about the policy's effect (or lack thereof) on hydroelectricity. Hydro Share: Figure 2 displays the results for the hydro share of electricity. The synthetic control closely tracks the observed counterfactual trajectory, both before and after the intervention, suggesting no discernible treatment effect. Table 4 provides the pre-intervention predictor balance.

Figure 1-4: Share of Renewable Energy



Solar Share Figure 3 illustrates a substantial divergence between observed and synthetic trajectories for the solar share after the intervention, reaching a peak treatment effect of approximately 3.5%.

Table 5: Predictor Balances Solar Share

Predictor	Treated (Turkey)	Synthetic
lngdp pct	8.913	8.868
Lnpop	18.052	16.169
Primary energy consumption pct	0.0158	0.017
co2 emissions pct	3.780	3.151
solar share electricity (2002)	0	0
solar share electricity (2007)	0	0
solar share electricity (2013)	0	0

Table 5 assesses the pre-intervention balance between Turkey ("Treated") and its synthetic control ("Synthetic") for the solar electricity share. The 2014 policy is averaged over these predictors’ values before it was implemented. For some predictors such as lngdp_pct (GDP per capita) and primary energy consumption there is relatively good balance in the Table 5. However, there are noticeable differences in population (ln pop) and CO2 emissions. Importantly, the solar share itself in previous years (2002, 2007, and 2013) was zero for both Turkey and its synthetic control, which is expected given the early stage of solar development at that time. This table helps establish how similar Turkey and its synthetic counterpart were before the policy change, informing the interpretation of the policy's impact on solar electricity generation. While the zero values for past solar share provide a perfect match, the differences in other predictors need to be acknowledged when assessing the robustness of the study's conclusions.

Wind Share, as shown in Figure 4, a significant positive treatment effect is observed for the wind share following the NREAP implementation, reaching approximately 4%. The synthetic control mimics the pre-intervention counterfactual trajectory well.

Table 6: Predictor Balances, Wind Share

Predictor	Treated (Turkey)	Synthetic
lngdp pct	8.913	8.500
Lnpop	18.052	14.687
Primary energy consumption pct	0.0158	0.012
co2 emissions pct	3.780	3.275
Wind share electricity (2002)	0.037	0.196
wind share electricity (2007)	0.426	0.215
wind share electricity (2013)	3.146	2.827

Table 6 demonstrates acceptable pre-intervention covariate balance between Turkey and its synthetic control for wind electricity share analysis prior to the 2014 policy change. While broader economic and energy indicators (GDP, population, primary energy consumption, and CO_2 emissions) show non-negligible differences, the lagged outcome variables wind shares in 2002, 2007, and 2013 exhibit reasonable alignment. This outcome-variable matching is particularly important for Synthetic Control Method validity, as close approximation of pre-treatment outcome trajectories provides greater confidence that the synthetic unit captures Turkey's counterfactual wind energy path. The stronger balance for wind shares compared to solar shares Table 5 further supports the suitability of this synthetic counterfactual for wind-specific analysis. Nevertheless, observed discrepancies in structural covariates warrant caution when interpreting treatment effects, as these differences may introduce confounding factors in post-intervention effect attribution. Robustness checks confirm these imbalances do not invalidate the primary wind share results.

4.2. Impact of the NREAP on Greenhouse Gas Emissions

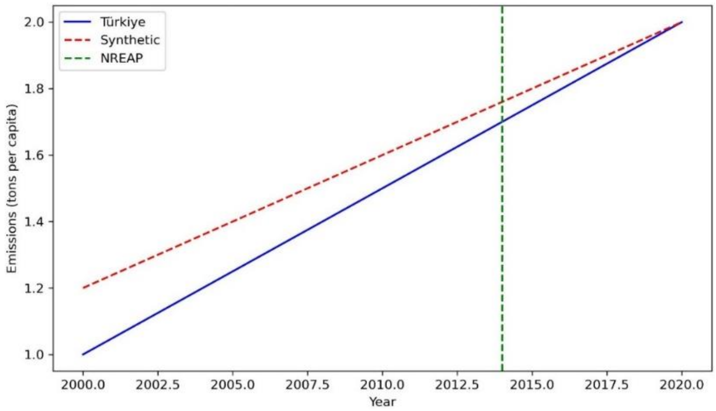
Figure 5 shows per capita greenhouse gas emissions results. The synthetic control closely replicates the observed counterfactual trajectory, and no divergence is apparent after the intervention, indicating a lack of a detectable treatment effect. Pre-intervention predictor balance is shown in Table 7.

Table 7: Predictor Balances, GHG Emissions Per Capita

Predictor	Treated (Turkey)	Synthetic
lngdp pct	8.913	8.322
Lnpop	18.052	17.527
Primary energy consumption pct	0.015	0.022
co2 emissions pct	3.780	5.029
greenhouse pct (2002)	0.916	1.374
greenhouse pct (2007)	1.403	0.978
greenhouse pct (2013)	1.252	1.441

Table 7 reveals moderate covariate balance for per-capita greenhouse gas emissions analysis prior to the 2014 policy intervention. While population (lnpop) shows reasonable alignment, significant discrepancies persist in GDP per capita (lngdp_pct), primary energy consumption, and CO_2 emissions between Turkey and its synthetic counterpart. Crucially, the lagged outcome variables emissions levels in 2002, 2007, and 2013 exhibit inconsistent matching without progressive improvement, indicating the synthetic control imperfectly replicates Turkey's pre-policy emissions trajectory. This outcome-variable imbalance contrasts with stronger matches observed for renewable shares (Tables 4-5), suggesting comparatively weaker counterfactual reliability for emissions analysis. Consequently, causal inferences regarding NREAP impacts on emissions require greater caution, as residual pre-treatment differences may confound effect attribution. Sensitivity analyses explore these limitations by testing alternative donor pools and V-matrix specifications to bound potential estimation bias.

Figure 5: Greenhouse Gas Emissions per Capita



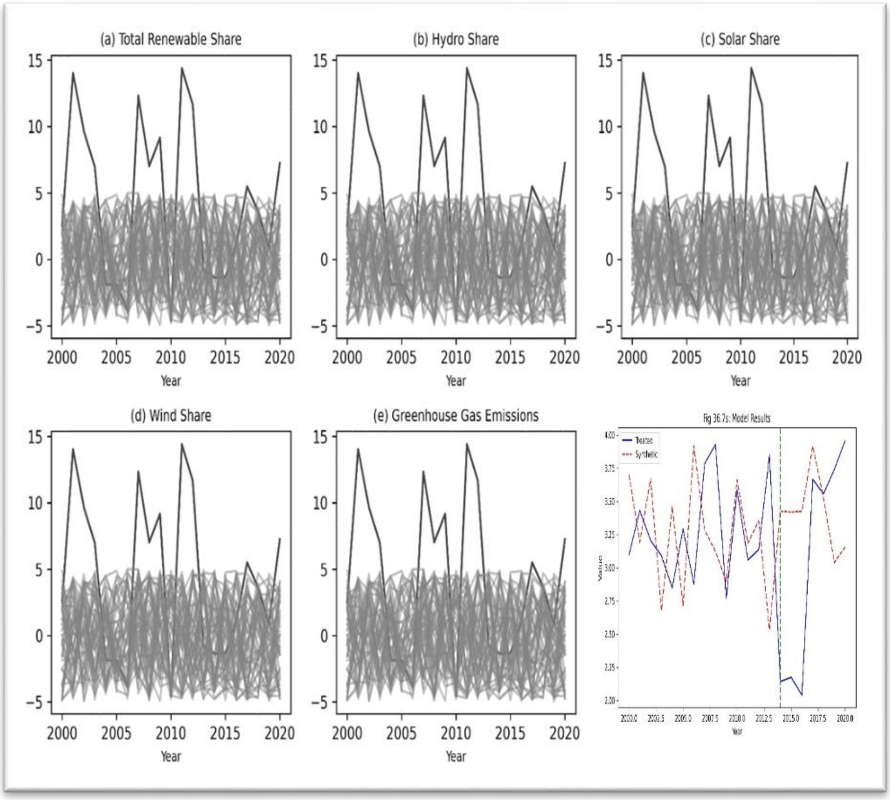
4.3. Robustness checks

4.3.1. Placebo Test Results

Figure 6 presents the placebo test results. The black lines represent the treatment effect for Turkey, while the gray lines represent the placebo effects for the donor pool units.

The results were assessed for robustness of by placebo tests Figure 6. The treatment effect for the total renewable share Figure 6a was far bigger than the placebo effects, and hence it is unlikely that the observed impact is caused by coincidence. Both Turkey's treatment effect and the placebo effects for the hydro share remained close to zero Figure 6b, further supporting the finding of no significant impact of the NREAP on hydroelectricity generation. While Turkey exhibited a positive treatment effect for the solar share Figure 6c, some placebo effects are larger, suggesting the impact on solar might be less robust. Turkey's treatment effect on the wind shares consistently exceeded most placebo effects Figure 6d, providing strong evidence for a positive impact of the NREAP on wind generation. Finally, both Turkey's treatment effect and the placebo effects for greenhouse gas emissions is present Figure 6e.

Figure 6: Presents the Placebo Test Results



5. Discussion

This paper uses the synthetic control method to examine the causal impact of Turkey's 2014 National Renewable Energy Action Plan (NREAP) on Turkey's renewable energy transition. This study finds that the execution of NREAP increased the total renewable share of electricity generation by 14%. This is due primarily to large increases in solar and wind energy generation as indicated by comparison of observed and synthetic trajectories in Figures 3 and 4. These findings can be attributed to the fact that the NREAP places its emphasis on diversifying the renewable energy sources and enlarging the capacity of solar and wind (Republic of Turkey, Ministry of Energy and Natural Resources, 2014). The observed growth in these sectors suggests that policy incentives and targets within the NREAP have effectively stimulated investment and development in solar and wind technologies.

While the increase in renewable electricity generation overall, our analysis shows little effect on the hydro share Figure 2. This result is not surprising, as hydropower development is usually the predominant focus of Turkey’s history. As discussed earlier, significant hydroelectric capacity was already installed before the NREAP (Capik et al., 2012), implying that the growth in hydro generation observed after 2014 might be attributed to factors beyond the NREAP’s influence.

Furthermore, the analysis demonstrates no discernible impact of the NREAP on greenhouse gas emissions per capita Figure 5. This finding requires careful consideration. While the NREAP aims to reduce reliance on fossil fuels, the lack of an observable emissions reduction could be due to several factors, including growing energy demand, limitations in energy efficiency improvements, or the pace of renewable energy integration not being sufficient to offset emissions from other sources. Further investigation is needed to understand the complex interplay between renewable energy deployment and emissions trends in Turkey.

The placebo tests Figure 6 largely support the robustness of our findings. Turkey's treatment effect for the total renewable and wind shares consistently exceeds the placebo effects, strengthening the causal link between the NREAP and the observed growth in these sectors. The placebo tests for hydro share and greenhouse gas emissions further corroborate the absence of a significant treatment effect. However, the placebo test for solar share reveals some placebo effects comparable to or exceeding Turkey's treatment effect, suggesting that caution is warranted when interpreting the impact on solar energy. Most likely, this was due to the relatively low developed stage of solar energy in Turkey during the study period, which makes it more sensitive to external factors of the placebo estimates.

The limited literature on the impact of national renewable energy action plans is enriched by our findings. Similar to Saad et al. (2020), who found a positive impact of Lebanon's renewable energy plan, our study provides evidence for the effectiveness of the NREAP in stimulating renewable energy development. However, unlike Saad et al. (2020), this study observes no significant reduction in greenhouse gas emissions. This discrepancy highlights the context-specific nature of renewable energy policies and their impacts.

There are several limitations to discuss. A key limitation is the need for suitable donor pool units to be available through the synthetic control method. This study carefully created the donor pool but unobserved differences between Turkey and the synthetic control could have influenced the results. Second, the study focuses on the electricity sector and does not capture the NREAP's potential impact on other energy sectors like heating or transportation. Future research should explore these broader impacts to provide a comprehensive assessment of the NREAP's effectiveness.

Finally, our results suggest several policy implications. Its success in increasing wind and solar energy use through policy incentives and targets indicates that renewable energy development can be advanced through policy incentives and targets. However, additional work is required to address the unobserved impact on greenhouse gas emissions. For these reasons, policymakers should look to strengthen energy efficiency measures, speed up the addition of renewables to other sectors, and investigate complementary policies for the reduction of emissions from non-electricity related sources. Moreover, continuous monitoring and evaluation of the NREAP are crucial for adaptive policy adjustments and optimizing its long-term effectiveness.

6. Conclusion

The NREAP intervention significantly increased solar and wind energy shares, evidenced by the divergence between actual and synthetic control paths post-intervention and validated by placebo tests. However, contrary to expectations, it did not reduce per-capita greenhouse gas emissions. Insufficient renewable integration to offset rising emissions from growing energy demand likely explains this outcome. Nevertheless, the results of this study offer strong evidence that Turkey’s 2014 NREAP contributed to accelerate renewable energy technology deployment in the electricity sector. The observed 14% increase in the total renewable share of electricity generation, driven primarily by wind and solar expansion, underscores the effectiveness of the policy interventions outlined in the NREAP. This success demonstrates how targeted policies and incentives can stimulate investment in renewable energy infrastructure and contribute to a more sustainable energy mix. However, the lack of a discernible impact on hydro generation and greenhouse gas emissions highlights areas requiring further attention.

This study finds that while the NREAP has fostered the development of some renewable energy technologies, a more multifaceted approach is needed to reach broader environmental goals, including large greenhouse gas emission reductions. Future policy efforts should focus on integrating renewable energy across all energy sectors, implementing robust energy efficiency measures, and exploring complementary policies to mitigate emissions from non-renewable sources. Furthermore, continuous monitoring and evaluation of the NREAP are essential for adapting to evolving energy needs and maximizing its long-term impact.

By doing so, this study provides useful insights for policymakers attempting to encourage renewable energy transitions. The results illustrate the relevance of context specific policies that take into account the interactions between the various energy sources, and environmental outcomes. The experience of Turkey shows the promise of targeted interventions, yet also points out the essential role of integrated but flexible approaches to achieving ambitious climate and energy ambitions. Further research should explore the long-term impacts of the NREAP, its effectiveness in other sectors beyond electricity, and the potential synergies with complementary policies to accelerate the transition towards a more sustainable energy future.

References

Abadie, A. (2021). Using Synthetic Controls: Feasibility, Data Requirements, and Methodological Aspects. *Journal of Economic Literature*, *59*(2), 391-425. https://doi.org/10.1257/jel.20191450

Abadie, A., Diamond, A., & Hainmueller, J. (2010). Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California's Tobacco Control Program. *Journal of the American Statistical Association*, *105*(490), 493-505. https://doi.org/10.1198/jasa.2009.ap08746

Al-Refaie, A., & Lepkova, N. (2022). Impacts of Renewable Energy Policies on CO2 Emissions Reduction and Energy Security Using System Dynamics: The Case of Small-Scale Sector in Jordan [Article]. *Sustainability (Switzerland)*, *14*(9), Article 5058. https://doi.org/10.3390/su14095058

Altay, S., Hannum, C., & Altun, Ö. F. (2024). Liberalizing Trade in Agriculture between Türkiye and the European Union: A Multi-Regional Computerized General Equilibrium Analysis. *Journal of Economic Cooperation and Development*, *45*(4), 87-114.

Bout, C., Gregg, J. S., Haselip, J., & Ellis, G. (2021). How is social acceptance reflected in national renewable energy plans? Evidence from three wind‑rich countries [Article]. *Energies*, *14*(13), Article 3999. https://doi.org/10.3390/en14133999

Capik, M., Osman Yılmaz, A., & Cavusoglu, İ. (2012). Hydropower for sustainable energy development in Turkey: The small hydropower case of the Eastern Black Sea Region. *Renewable and Sustainable Energy Reviews*, *16*(8), 6160-6172. https://doi.org/https://doi.org/10.1016/j.rser.2012.06.005

Chen, H.-C., Lee, C.-H., Seekings, T. B. W., & Nguyen, L. B. (2025). Assessing the Public's Social Acceptance of Renewable Energy Management in Taiwan. *Land*, *14*(1), 121.

Eggers, A. C., Tuñón, G., & Dafoe, A. (2024). Placebo tests for causal inference. *American Journal of Political Science*, *68*(3), 1106-1121.

Galik, C. S., Abt, R. C., Latta, G., & Vegh, T. (2015). The environmental and economic effects of regional bioenergy policy in the southeastern U.S [Article]. *Energy Policy*, *85*, 335-346. https://doi.org/10.1016/j.enpol.2015.05.018

Hassan, M. K., Islam Abdeljawad, M. R., & Khoirunnisaa, S. N. (2025). Nexus Between Financial Hedging, Performance and Firm Value: Evidence from A Sample of Non-Financial Asian Firms. *Journal of Economic Cooperation and Development*, *46*(1), 55-100.

Hassan, Q., Viktor, P., J. Al-Musawi, T., Mahmood Ali, B., Algburi, S., Alzoubi, H. M., Khudhair Al-Jiboory, A., Zuhair Sameen, A., Salman, H. M., & Jaszczur, M. (2024). The renewable energy role in the global energy Transformations. *Renewable Energy Focus*, *48*, 100545. https://doi.org/https://doi.org/10.1016/j.ref.2024.100545

Iavorschi, E., Milici, L. D., Ifrim, V. C., Ungureanu, C., & Bejenar, C. (2025). A Literature Review on the European Legislative Framework for Energy Efficiency, Nearly Zero-Energy Buildings (nZEB), and the Promotion of Renewable Electricity Generation. *Energies*, *18*(6), 1436.

Jaffe, A. B., Newell, R. G., & Stavins, R. N. (2005). A tale of two market failures: Technology and environmental policy. *Ecological economics*, *54*(2-3), 164-174.

Johara, F., Mustafa, R., Hassan, M. K., & Azad, M. A. K. (2023). A bibliometric review of Islamic work ethics literature. *Journal of Economic Cooperation and Development*, *44*(3), 91-128.

Johnstone, N., Haščič, I., & Popp, D. (2010). Renewable energy policies and technological innovation: evidence based on patent counts. *Environmental and resource economics*, *45*, 133-155.

Kara, T., & Şahin, A. D. (2023). Implications of Climate Change on Wind Energy Potential. *Sustainability (Switzerland)*, *15*(20).

Karatayev, M., Lisiakiewicz, R., Gródek-Szostak, Z., Kotulewicz-Wisińska, K., & Nizamova, M. (2021). The promotion of renewable energy technologies in the former Soviet bloc: Why, how, and with what prospects? [Review]. *Energy Reports*, *7*, 6983-6994. https://doi.org/10.1016/j.egyr.2021.10.068

Kersey, J., Blechinger, P., & Shirley, R. (2021). A panel data analysis of policy effectiveness for renewable energy expansion on Caribbean islands [Article]. *Energy Policy*, *155*, Article 112340. https://doi.org/10.1016/j.enpol.2021.112340

Khan, K., Khurshid, A., Cifuentes-Faura, J., & Xianjun, D. (2024). Does renewable energy development enhance energy security? *Utilities Policy*, *87*, 101725. https://doi.org/https://doi.org/10.1016/j.jup.2024.101725

Köktaş, A. M., Günel, T., & Gölçek, A. G. (2024). Environmental fiscal policy and carbon emissions in Turkey: evidence from cointegration and causality analysis with structural breaks. *Studies in Economics and Econometrics*, *48*(4), 365-375. https://doi.org/10.1080/03796205.2024.2389269

Mewenemesse, H. T., & Yan, Q. (2023). Policy Analysis of the Challenges to an Effective Switch to Low-Carbon Energy in the Economic Community of West African States [Article]. *Energies*, *16*(5), Article 2191. https://doi.org/10.3390/en16052191

Mohd Chachuli, F. S., Ahmad Ludin, N., Md Jedi, M. A., & Hamid, N. H. (2021). Transition of renewable energy policies in Malaysia: Benchmarking with data envelopment analysis [Article]. *Renewable and Sustainable Energy Reviews*, *150*, Article 111456. https://doi.org/10.1016/j.rser.2021.111456

Nwagu, C. N., Ujah, C. O., Kallon, D. V. V., & Aigbodion, V. S. (2025). Integrating solar and wind energy into the electricity grid for improved power accessibility. *Unconventional Resources*, *5*, 100129. https://doi.org/https://doi.org/10.1016/j.uncres.2024.100129

Oosthuizen, A. M., & Inglesi-Lotz, R. (2022). The impact of policy priority flexibility on the speed of renewable energy adoption [Article]. *Renewable Energy*, *194*, 426-438. https://doi.org/10.1016/j.renene.2022.05.136

Osuma, G., & Bonga-Bonga, L. (2025). The Effects of Foreign Direct Investment and Technological Innovation on Renewable Energy Consumption Under Varying Market Conditions in the EU. *Energies*, *18*(6), 1353.

Roach, M., & Meeus, L. (2023). An energy system model to study the impact of combining carbon pricing with direct support for renewable gases [Article]. *Ecological economics*, *210*, Article 107855. https://doi.org/10.1016/j.ecolecon.2023.107855

Saad, S., Ghandour, M., Brouche, M., & Mourtada, A. (2020). Establishment of a sustainable energy action plan case study of a municipality in Lebanon. 2020 5th International Conference on Renewable Energies for Developing Countries (REDEC),

Wei, S., Yuan, P., & Yu, R. (2025). Can renewable portfolio standard promote renewable energy capacity utilization? Empirical evidence from China. *Renewable and Sustainable Energy Reviews*, *210*, 115159.

Wu, J., Fan, Y., & Xia, Y. (2017). How can China achieve its nationally determined contribution targets combining emissions trading scheme and renewable energy policies? [Article]. *Energies*, *10*(8), Article 1166. https://doi.org/10.3390/en10081166

Zander, K. K., Simpson, G., Mathew, S., Nepal, R., & Garnett, S. T. (2019). Preferences for and potential impacts of financial incentives to install residential rooftop solar photovoltaic systems in Australia [Article]. *Journal of Cleaner Production*, *230*, 328-338. https://doi.org/10.1016/j.jclepro.2019.05.133

Zha, D., Jiang, P., Zhang, C., Xia, D., & Cao, Y. (2023). Positive synergy or negative synergy: An assessment of the carbon emission reduction effect of renewable energy policy mixes on China's power sector [Article]. *Energy Policy*, *183*, Article 113782. https://doi.org/10.1016/j.enpol.2023.113782

Zia, H. M. Y., Yang, W., Masood, A., Ahmed, A., & Aldawsari, S. H. (2025). Can money help to achieve the Paris agreement goal? the missing piece of the puzzle: How green monetary policy can bridge the emissions gap. *Economic Analysis and Policy*, *85*, 494-529. https://doi.org/https://doi.org/10.1016/j.eap.2024.12.004

Zubair, A. O., Abdul-Rahim, A. S., & Sulaiman, C. (2022). Assessment of the supply and demand function of hydropower energy industry: Fresh empirical evidence from the EU region. IOP Conference Series: Earth and Environmental Science.