Essays on Renewable Energy, Emissions and Policies

by

Oladimeji Tomiwa Shodipe

B.Sc., University of Lagos, 2016
M.A., Eastern Illinois University, 2019

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Economics
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KANSAS STATE UNIVERSITY
Manhattan, Kansas

2025

Abstract

This dissertation consists of three essays on renewable energy expansion, emissions, economic performance, policy frameworks, and macroeconomic shocks across U.S. states. The first chapter studies the impact of renewable energy generation on electricity prices and economic activities in the U.S. The second chapter explores the relationship between state-level energy efficiency policies, disclosure policies and emissions in the U.S. The third chapter examines the impact of monetary shocks on the variations in renewable energy capacities.

The first essay examines renewable energy generation and the economic and price impacts across U.S. states. Given the wide variation in renewable energy expansion and efficiency performance, the chapter employs the American Council for an Energy-Efficiency Economy (ACEEE) Scorecard and state-level political and policy indicators to classify states according to their renewable adoption and efficiency programs. Using a heteroscedasticity-identified structural vector autoregression (SVAR), the analysis finds that states in the upper developmental stage of renewable energy benefit more economically from renewable investments, experiencing increased economic activity and reduced electricity prices. States where renewables compete with conventional sources exhibit stronger responses. The findings in this study underscore the need for continued investment in clean energy technologies.

The second essay investigates the effects of state-level energy efficiency policies, disclosure mandates, and political orientation on greenhouse gas (GHG) emissions between election cycles. This chapter finds that states adopting energy disclosure policies achieved significant emissions reductions in Democrat-led states. Energy efficiency improvements in the transportation sector emerged as the only statistically significant factor driving GHG reductions

among all the five policy areas considered in this study. These findings highlight the importance of targeted efficiency programs in emissions reductions.

The third essay analyses the impact of unanticipated monetary policy shocks on renewable energy capacity. While previous studies have investigated the effects of monetary shocks using various instruments, this chapter offers a novel perspective by examining the influence of treasury-based measures. The empirical results show that monetary shocks statistically cause changes in renewable energy capacities. Disaggregated analysis reveals that monetary shocks significantly influence hydroelectric and bio-energy capacities, while wind and solar remain largely unresponsive to monetary shocks. These findings suggest that renewable infrastructure is not immune to broader economic fluctuations.

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Dedication

This work is dedicated to my wife, Iyanu Farukanmi Shodipe, my son, Oreluwa Shodipe and my parents, Mr. and Mrs. Shodipe, whose love and inspiration have been my greatest strength.

1 Renewable Energy Generation, Electricity Price, and Economic Activities in the U.S.

1.1 Introduction

In the last two decades, the global economy has shifted from fossil fuels to safer and more efficient alternative energy (Qi *et al.,* 2024; Periasamy & Mohanta, 2024). The transition towards renewable energy is accorded to the energy crisis, the global campaign to reduce carbon footprint and the threat to climate conditions (Olabi & Abdelkareem, 2022; Ozili & Ozen, 2023; Wei et al., 2024). The need to provide a clean, reliable, and reasonably priced energy supply has led to more adoption of renewable energy (Bogdanov et al., 2021). Although the transition has been somewhat snail-paced, the apparent desirability of more renewable and sustainable energy seems to be more intriguing as more scholars find impacts on the economy (Shahbaz *et al.,* 2020; Raihan, 2023; Shah *et al.,* 2024). For example, Blazejczak et al. (2014) reveal that renewable energy expansion increases net job growth in Germany, particularly during tight labor market conditions.

Renewable energy is essential to sustainable energy development and the environment (Su *et al*., 2022). According to the latest Renewables 2023 Global Status Report (GSR), global additions to renewable power capacity increased by an estimated 13.9%, reaching a net increase of 473 gigawatts (GW), a new record for the 22nd consecutive year, while non-renewable energy with a net gain of 75 GW.

Renewables are crucial for the energy supply in the United States economy. Although traditional energy sources continue to account for a significant portion of energy usage in the U.S., a substantial share of generated electricity comes from clean energy sources. For instance, in 2022, the constituent of renewable energy in the total energy consumption in the U.S. was about 13.18 quadrillion British thermal units (btu), with renewable energy contributing about 21% of the total

U.S. electricity generation[1]. However, promoting energy sustainability through low-carbon and cost-effective energy has uncertain economic implications due to renewable energy's technological and climate-related financial risks (Sachs et al., 2019). Moreover, we have seen corroborating evidence from recent studies which show demonstrably different side-effects of the energy transition to renewable sources in various states of the U.S (Idoko *et al.,* 2024; Hassan *et al.,* 2024; Usiagu *et al*., 2024; Abbasi et al., 2024).

The studies on the relationship between economic growth and expansion in renewable energy are not new and have had conflicting successes in recent decades. Bhattacharya et al. (2016) utilized aggregate renewable energy. Their study shows that the output-renewable energy elasticity was -0.072 in the United States between 1991 and 2012. On the other hand, some recent studies have demonstrated a positive relationship between sustainable energy and economic growth. For example, Wang et al. (2022) highlighted that renewable energy stimulates economic growth. The common denominator found in these studies is the assumption of homogeneity among the states in the U.S. and across many countries. However, this assumption is not always valid, as states are at different stages of renewable energy development. Given the lack of uniformity in findings, this study extends the literature through an analysis focusing on the impact of renewable energy based on the efficiency characteristics and development stage unique to a group of states.

Most literature that has examined energy development and the economy in the U.S. has often overlooked heterogeneity in the state's capacity and infrastructures to produce energy, leading to aggregation bias in results and findings. For example, states rich in resources like wind or sunlight have a comparative advantage in renewable energy production, making their

[1] U.S. Energy Information Administration. (2023). Monthly energy review. Retrieved from https://www.eia.gov/totalenergy/data/monthly/archive/00352212.pdf

development trajectory different from states with fewer resources. Some states lacking in-state conventional fossil energy resources have diversified their energy sources, while states with historically low-cost conventional energy resources have deployed fewer renewables in their energy mix (Eldridge et al., 2007). On the other hand, early development states may experience higher initial and overhead costs, infrastructure and structural challenges, and higher energy prices. At the same time, those with more mature renewable sectors benefit from economies of scale and learning-by-doing effects, reducing their marginal costs over time. Similarly, states in the U.S. are at different stages of development, leading to varying degrees of network and spillover effects of renewable energy. For instance, states with more advanced sectors may experience faster innovation, job creation, and rapid growth in complementary industries with an enormous investment in renewable energy. States with mature renewable energy industries that have excelled so well in energy efficiency are also likely to have supportive regulatory environments and policy frameworks that drive further development. However, states with historically lower prices may not have the same pressure to make aggressive investments in clean energy (Berg et al., 2006).

Giving a context to the heterogeneity in development and impact of renewables in the U.S, California, Massachusetts, Vermont, New York, Oregon, Connecticut and Rhode Island, which have ranked on top for 15 consecutive years and are among the top ten states in Energy Efficiency Score of the American Council for an Energy-Efficient Economy (ACEEE), have experienced a consistent expansion in the economic activities captured by the Gross Domestic Product (GDP) across all sectors. The states in this tier demonstrated multisectoral leadership in energy efficiency, bordering on utility programs, transportation, building codes, and state government initiatives (Relf et al., 2020). However, some states with higher ACEEE energy efficiency rankings have historically experienced increasing electricity prices. This price rise could be due to a lack of traditional in-state energy resources, early investment in new renewable technologies and infrastructure, or the higher costs associated with implementing energy efficiency measures (Ratepayer-funded energy efficiency programs). Supporting the mixed results from previous studies, states like Massachusetts experienced electricity price increases from 18.19 cents/Kilowatt-hour (kWh) in 2017 to 18.50 cents/kWh in 2019 [2]. California and Oregon also saw a price increase or minimal change during this period. Rhode Island experienced a sharp drop between 2019 and 2020, from 18.10 to 16.42 cents/kWh, showing a trend like Massachusetts. However, increases in energy costs do not necessarily hinder economic activity if energy is used efficiently because improved energy efficiency enhances total factor productivity and drives economic growth on a larger scale (Cantore et al., 2016; Irfan, 2021). Energy efficiency policies improve the state's economic impact of renewable energy in multiple ways. These policies promote clean energy use, boost the purchasing power of households and businesses and encourage sustainable growth through reduced energy costs. Policy initiatives, such as combined heat and power system programs, prioritize renewable energy, make grid integration more seamless, minimize transmission costs and the bottleneck on energy infrastructure, and ultimately attract more private investments into the green energy sector.

Based on the interesting dynamics in the historical experience of states in the U.S., re-evaluating the growth impact of renewable energy on output and the changes in energy prices, specifically electricity prices, can inform policymakers on how to direct renewable investment programs. In other words, understanding the crucial impact of renewable energy on output and electricity prices could inform policymakers on how to promote low-carbon energy systems and guide the development of policies that stimulate growth and reduce household energy costs.

[2] 2017 to 2020 Electricity Data - U.S. Energy Information Administration (EIA).

Additionally, a proper understanding of the variabilities in electricity prices due to renewable energy production is essential for electricity providers to hedge against the risk of price fluctuations (Johnson and Oliver, 2019). At the same time, understanding the economic benefits of renewable energy is crucial for effectively allocating economic resources and proposing risk-management techniques for electricity price stability. The International Renewable Energy Agency (IRENA) highlighted that the solar photovoltaic (PV) electricity cost between 2010 and 2020 fell by 85%, resulting from technological improvements[3] and more renewable energy expansion. Therefore, as the share of renewable energy in the energy mix grows, understanding its dynamic impact provides insights for developing hedging mechanisms and regulatory frameworks that protect consumers and renewable energy producers, as well as ensure grid reliability.

This study expands on the literature on renewable energy-economy nexus, utilizing the energy efficiency ranking and renewable energy policies of the states in the U.S. to categorize states into homogenous groups. In other words, this paper classifies the impacts of renewable energy on economic activities and electricity prices based on the efficiency metrics developed by ACEEE and the progressive nature of states towards clean energy. This study performs a structural vector autoregressive model (SVAR) and generates shock responses using the Generalized Method of Moments (GMM). Additionally, this study reviews and employs recursive and heteroscedasticity identification strategies to illustrate dynamics in the economy from the different shock levels. However, the heteroscedasticity method is preferred over the recursive approach because it imposes no restriction assumptions and the ability to account for potential transitions in renewable energy.

[3] IRENA (2020). Renewable Power Generation Costs in 2020. International Renewable Energy Agency.

The analysis of this study shows that expansion in renewable energy impacts economic activities in the U.S. The results revealed that the economic activities and electricity prices in the states that rank higher in energy efficiency scores responded more to an increase in renewable energy than states that rank lower in energy efficiency. In other words, states that have historically experienced higher electricity prices but have invested in energy efficiency programs and renewable energy show more significant economic gains than states with lower energy efficiency performance. Furthermore, states in the second tier in policy areas, using an average year-over-year score, responded more to shocks than the first tier. In other words, states that combine low-cost conventional sources with renewable energy expansion experience downward pressure on electricity prices.

1.2 Literature

The interplay amongst the key variables of renewable energy, electricity prices, and productivity has been in the limelight of literary discussion for a few years. Several studies have attempted to explore this complex interaction. Electricity prices may drop when low-cost renewables like wind and solar supplement high-cost conventional power during low reservoir seasons (Afonso *et al.,* 2019). An increased reservoir level of efficient energy generation can also result in declining electricity prices. These situations generally result in energy stability, which, in turn, drive economic growth through a short-course transmission mechanism (Nadel *et al.,* 2015).

The varying outcomes seen in past studies, as explained in the previous section, are strongly connected with the evidence that not all the states in the U.S. have attained the steady-state stage of growth for renewable energy supply, economic development, and reduced electricity prices. While some may have attained and stuck at lower state-stage growth. The reason is documented in Jacobsson & Lauber (2006), which revealed that adopting renewable energy and its socio-economic impact varies widely by the nature of economic and political environments.

At a steady state level - an efficiently optimized supply of renewable energy - economies are bound to experience sustainable growth driven by innovation and technological improvement, reduced cost of operations, and reduced environmental cost. The steady and consistent integration of renewable energy into the energy mix in this economic stage reduces electricity prices, further stimulating economic growth by lowering production costs, increasing demand through increased consumer purchasing power, and boosting industrial competitiveness.

Thus, the transition to renewable energy creates a virtuous cycle: renewable energy drives growth, growth encourages further investment in renewables, and falling electricity prices sustain long-term economic prosperity (Trujillo-Baute *et al.,* 2018). However, reaching this state is constrained by the capital outlay of renewable energy technologies, energy storage facilities, grid infrastructural requirements and relevant policy support. In the context of the U.S., states differ significantly in ambition towards renewable energy development, thus limiting attaining a steady state with renewable energy.

While some states, such as California, have made significant strides in renewable energy adoption, other states are still heavily reliant on fossil fuels. California, for instance, leads the nation in solar energy capacity, with more than 32% of its electricity coming from solar in 2022[4]. On the other hand, Wyoming relies on coal for 85%[5] of its electricity generation.

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[4] U.S. Energy Information Administration. (2024, October 23). *California Electricity Profile 2023*. U.S. Department of Energy. https://www.eia.gov/electricity/state/california/

U.S. Energy Information Administration. (2023 October 23). *Wyoming Electricity Profile 2023*. U.S. Department of Energy. https://www.eia.gov/electricity/state/california/

The stylized facts in Table 1:1 provide a factual overview of the status of some leading states based on their progressiveness, renewable energy generation and trends in their expansion and retail electricity prices.

Table 1:1 Stylized Fact on Output and Average Electricity Prices U.S. Top Ranked States in Renewable Energy

Top States	Renewable Energy generation* in "000" GW/h		Electricity Price in cents per kWh (All Sector)		GDP Per State in Million USD	
	2017	**2020**	**2017**	**2020**	**2017**	**2020**
Texas	70827	102353	8	8	1667313	1798596
California	54544	60871	16	18	2740550	3068809
Iowa	21587	34412	9	9	187125	199447
Oklahoma	23930	29833	8	8	192539	191654
Minnesota	13666	14621	10	11	354722	379439
Illinois	12794	16696	9	10	832827	860748
Washington	8824	10700	8	8	527169	621493
Oregon	7576	11008	9	9	225535	251856
Colorado	10435	15056	10	10	350209	397612
Michigan	7749	8992	11	12	505102	530231
New York	6605	7322	15	15	1624801	1766857
Pennsylvania	6098	5799	10	10	754318	777427
Florida	5886	10535	10	10	1014867	1140133

Source: U.S. Energy Information Administration.
Note: * implies total renewable excluding conventional hydropower

The stylized fact (Table 1:1) shows the renewable energy generation across the top 13 states with the largest generation capacity, electricity prices, and Gross State Products. Renewable energy, electricity prices, and GDP growth reveal differing patterns across U.S. states. In some states, reduced electricity prices and consistent GDP expansion complement increased renewable energy generation, while in others, the outcomes are less aligned. This fact supports the development of methods for grouping based on shared characteristics.

In states like Texas and Oklahoma, there is evidence of complementarity between rising renewable energy output, dipping electricity prices, and GDP growth. For instance, Texas saw a stunning surge in renewable energy generation, increasing to 102,353 GWh in 2020 from 70,827 GWh in 2017. Meanwhile, electricity prices remained stable or faintly declined, crashing from 8.60 to 8.36 cents per kWh by 2020. During this period, the state's GDP continued to grow, showing how economies of scale, improved innovation, technological advancement, and infrastructure investments in renewable energy can help reduce energy costs while driving economic expansion.

Similarly, Oklahoma saw a renewable energy growth, with generation rising from 23,930 GWh in 2017 to 29,833 GWh in 2020, GDP expanding to 205 billion USD in 2019 from 192.5 billion USD in 2017 and electricity prices declining from 8.20 cents per kWh in 2017 to 7.63 cents per kWh in 2020. This fact highlights how increased renewable capacity correlates with economic growth by reducing the cost burden of energy on industries and households.

However, the relationship between energy generation and prices is more complex in California, with strong renewable energy growth. Despite increased renewable energy production, electricity prices rose from 16.06 to 18.00 cents per kWh during the same period, though the state's GDP remained high. As a state with limited traditional energy resources, California has historically experienced high energy prices (Eldridge et al., 2007). Factors such as grid modernization costs and counteractive regulatory policies can also affect to the price-lowering effects of renewable energy growth. In the early days of renewable energy, installing technologies like wind turbines and solar panels was costly and inefficient due to high technology costs[6]. As a result, states that

[6] Centers for Rural Affairs, Fact Sheet: Renewable Energy and You: Declining Costs. https://www.cfra.org/sites/default/files/publications/renewable-energy-and-you-declining-costs-1.pdf

initially invested in these technologies may still be grappling with servicing higher capital costs, which, in turn, contribute to higher energy prices. Nonetheless, the increase in electricity prices has become less as the state continues to integrate renewable energy and invest in efficient alternative energy sources.

Intuitively, renewable energy alternatives are expected to reduce electricity prices for several reasons. Although these sources offer long-term benefits, the increasing integration of renewable energy often involves significant upfront costs for grid modernization and storage solutions, which can raise electricity prices in the short term. Moreover, state utility regulators frequently adjust rates based on recent costs incurred by electric utilities. Expanding electricity demand, underscored by many devices running purely on electricity utilities, can increase prices *(Energy Information Administration (EIA)* 2024). The complementarity between energy generation, prices, and GDP depends heavily on state-specific factors like energy infrastructure (low-cost conventional and renewable energy technology) and regulatory frameworks.

Before concluding on the dynamics and complexities of the impact of renewable energy, it is essential to understand the findings in the literature to gain perspective on the impact of renewable energy on macroeconomic activities and how this study fits in. Generally, previous papers have made significant efforts to investigate the effects of renewable energy generation on electricity prices in the U.S. but have made little effort to consider heterogeneities among the states and how they may impact the results. Therefore, this study contributes to the literature by considering average year-over-year scores across all policy areas[7] reported in ACEEE scorecards from 2006 to 2020 to group states into different categories, then examining the effects of renewable

[7] utility and public benefits programs and policies, transportation policies, building energy efficiency policies, combined heat and power (CHP) policies, state government–led initiatives around energy efficiency and appliance and equipment standards

energy on economic output and electricity prices across each state grouping using heteroscedasticity – identified structural vector autoregression. Grouping states becomes imperative when comparing individual impact is impossible. The state grouping approach enables the analysis of renewable energy across states to be less ambiguous because it already consolidates the differences such as development stages, economies of scale and learning curves, spillover effects, and policy and regulatory variations in all the states in the U.S. Suffice to say this approach potentially mitigates aggregation and disaggregation biases at the same time, ensuring a more accurate reflection of the growth impact of the renewable energy sources.

Past literature has yielded an inconclusive outcome on the effect of the renewable energy share on electricity price and productivity as fundamental drivers like market structure, regulatory policies, and varying climatic conditions are critical to the growth impact of renewable energy generation (Trujillo-Baute, del Río, & Mir-Artigues, 2018).

Johnson and Oliver (2019) performed panel analysis utilizing panel data from 19 countries from 2000-2011, including data from the northeast of the U.S. The authors employed instrumental variable (IV) and OLS estimation techniques to determine the impact of the share of wind and solar of the total generation capacity on the quarterly variance of daily wholesale electricity prices. The study identified a positive relationship between quarterly wholesale price variance and wind and solar energy capacity when utilizing IV. Their results suggest that the intermittency effect outweighs the stochastic merit-order effect, ultimately driving up energy prices. Conversely, the study found a negative relationship using the OLS method, suggesting that the stochastic merit-order effect dominates the intermittency effect. The authors offered explanations for the divergence in the results of the IV estimation by highlighting the presence of reverse causality bias in OLS estimates.

The evidence of merit-order effects in the many studies raises concerns about whether estimation methods were the primary reason for conflicting results, as found in Johnson and Oliver (2019). Other influential studies, such as Cludius et al. (2014), Rivard and Yatchew (2016) and Figueiredo and da Silva (2019), have used OLS, generalized additive model (GAM), and GARCH, respectively, and showed evidence of merit-order effects and their price-reduction impact.

In the case of Spain, Ballester & Furio (2015) found that a growing proportion of renewable energy led to reduced electricity prices at the retail level from 2010 to 2013, considering "peak and off-peak prices" independently. Contrastingly, the study reports that this was not the case from 2002 to 2009 due to the less severe use of renewable technologies and the more significant costs linked with these technologies during this time. This study shows that renewable energy sources increased from 29% to 59%, accounting for up to 80% of the daily supply on several occasions since 2011. They adopted Cartea & Figueroa's (2005) model, a stochastic process with mean reversion that includes a discrete jump process that captures price volatility. They concluded that the relationship between the share of renewable energy and electricity prices was not only significant for peak prices. This study also found a significant positive relationship between price volatility and nuclear, hydroelectric, combined cycle, and thermal energy.

Apergis and Danuletiu (2014) conducted a multi-country dynamic error correction analysis to study the relationship between renewable energy consumption and GDP growth in 80 countries, including the U.S. The authors found strong evidence of a bi-directional causality between renewable energy consumption and economic growth.

However, the study conducted by Bhattacharya et al. (2016) countered the positive relationship between renewable energy and economic growth in the U.S. between 1991 and 2012. Some studies using panel analysis have also found varying results. For example, Ohler and Fetters

(2014) used dynamic OLS, fully modified OLS, and error correction estimation techniques to investigate the relationship between renewable energy and economic growth in 20 OECD countries. The authors found bidirectional causality between energy from renewable sources and real GDP. Still, they showed that when accounting for cross-sectional dependence, there is evidence of a negative relationship between biomass, waste generation, and GDP. These conflicting evidence and disparities in findings create a gap in the literature.

Much previous work has modeled the relationship between macroeconomic activities and renewable energy at the aggregate level. However, using state-level data and ranking the states by their efficiency performance to capture the impact of heterogeneity in renewable development provides valuable insights into how the adoption of renewable energy varies and how policymakers can direct renewable programs in different states. Furthermore, the inconsistencies in previous findings suggest that attempts to understand the relationship between renewable energy and economic growth without accounting for factors such as energy prices—particularly electricity price volatility—and pre-existing structural and institutional background may lead to unreliable conclusions. This study, therefore, models the relationship between renewable energy and macroeconomic activities while accounting for the intermediate role played by electricity price dynamics across all states. Equally, in contrast to previous work, this study offers an alternative strategy for identifying the impact of renewable energy on economic activities and electricity prices, recognizing the recent transition in the utilization of renewable energy in recent years.

1.3 Data and Model

First and foremost, many previous papers have used yearly data to study the impact of renewable energy, primarily due to the limited availability of data on renewable energy. However, this study aims to capture short to midterm dynamics, a cumulative two-year response to shock, in the VAR model. Therefore, this study utilizes monthly data. Modeling moderately-frequency data accurately estimates the short-term dynamics in the VAR model (Gertler and Karadi, 2015). Equally, monthly data is preferred in this paper because it is difficult to justify the timing restrictions in low-frequency (annual) data. The preference for monthly data never suggests that the results from restriction assumptions are not robust to low-frequency data in a much larger sample. Furthermore, no insightful information will be gained using high-frequency data because expansion in renewable energy generation and their effect on the economy require some lead time.

The data used in this study includes monthly total renewable energy (Megawatt/hours) and wholesale electricity prices (cents/kWh) from the Energy Information Administration (EIA) and the de-seasonalized Coincidence Economic Activity Index (CEAI). The total renewable energy electricity generation (Rew) data is the accumulation of all electricity generated from renewable sources such as wind, solar, hydro, wood, geothermal, and biomass. The renewable energy electricity generation data is converted to percentage. The wholesale electricity prices (EnerP) are adjusted for inflation using the consumer price index for urban consumers.

The data on economic activity is represented by the monthly Coincident Economic Activity Index (Y), measured by the weighted average of composite economic indicators such as employment, industrial production, and retail sales and obtained from the Federal Reserve Economic Data (FRED). While Gross Domestic Product (GDP) is commonly used to measure economic activity, monthly GDP data is not available for all states in the U.S. Some previous papers considered CEAI as the second-best measure of economic activities after GDP, such as Melichar (2016).

The lack of complete monthly state-level data limits the sample used in this study to the period between 2001 and 2021. Due to the significant number of missing values, Delaware, Washington D.C., and Puerto Rico are dropped from the sample.

The grouping of states – Table 1:2 shows the categorization of states according to their energy efficiency performance, policies, and political leanings.

ACEEE Ranking: States were ranked based on their energy efficiency performance. States are grouped into top-performing states (Ranks 1–10), mid-tier performers (Ranks 11–20), lower-performing states (Ranks 31–40), (Ranks 41–49) based on their scores in six policies area: utility and public benefits programs and policies, transportation policies, building energy efficiency policies, combined heat and power (CHP) policies, state government-led initiatives around energy efficiency and appliance and equipment standards. This ranking system allows for comparing states' commitment and progress in energy efficiency. While it is feasible to analyze state data and compare with results with another states, this study considers it more useful to analyze the differences between states in groups. The reason is that the gap in efficiency scores between these groups is typically more significant than the differences between individual states within the same group (Downs et al., 2013). Essentially, understanding rankings at a broader level provides clear insights than focusing on variations between states.

Political Party: The states are also divided based on the predominant political party, as energy policies often align with political ideologies. In this study, it is assumed that Democrat-led states tend to support more aggressive climate policies. In contrast, Republican-led states may take a more conservative approach to energy regulations and standards. However, the challenge with using political affiliation is that we cannot argue it ultimately determines the trend in renewable energy investment in the U.S. Another caveat to using this approach is the potential introduction of selection bias into the grouping. Policies on renewable energy are influenced by many factors, such as the state's policy actions, and economic, geographic, and market conditions. While Democrat-led states often advocate for climate policies and energy efficiencies, we have seen some Republican-led states like Iowa, Texas, Kanas and Iowa have significantly invested in wind and solar power. Nevertheless, analyzing energy policies through a political lens provides benefits such as identifying growth trends in states with similar political ideologies and efficiency programs. By understanding the economic benefits of renewable energy in states that have gained historical credits for leading renewable energy expansion, policymakers can develop better programs that engender more economic growth.

Table 1:2 Method of Grouping

Methods	Rank/Category	States
ACEEE Ranking[a]	Ranks 1- 10	CA, MA, VT, NY, RI, WA, MN, MD, CT, OR
	Ranks 11- 20	ME, CO, HI, NJ, IL, PA, MI, UT, AZ, NH
	Ranks 21- 30	WI, IA, NM, NV, NC, FL.ID, TX, VA, OH
	Ranks 31- 40	MT, TN, NE, KY, ID, AR, GA, OK, MO, SC
	Ranks 40- 49	AK, SD, AL, WV, LA, KS, MS, ND, WY
ACEEE Ranking Two categories)	Ranks 1- 25	CA, MA, VT, NY, RI, WA, MN, MD, CT, OR, ME CO, HI, NJ, IL, PA, MI, UT, AZ, NH, WI, IA, NM, NV, NC
	Ranks 25- 49	MT, TN, NE, KY, IN, AR, GA, OK, MO, SC, FL, ID, TX, VA, OH, AK, SD, AL, WV, LA, KS, MS, ND, WY
Political Affiliation[b]	Democrat	CA, NY, IL, MA, VT, MD, OR, WA, CT, RI
	Republican	WY, UT, ID, NE, OK, ND, SD, KS, AL, MS

a. State Energy Efficiency Scorecard: Average of three period (2010, 2015, 2020). b. Classification based on the summary of statewide results of the 2008, 2012, 2016, and 2020 presidential elections by state: Database of States Incentives for Renewable Energy (DSIRE). https://programs.dsireusa.org/system/program
Note: American Council for an Energy-Efficiency Economy (ACEEE).
ACEEE's indices are utility and public benefits programs and policies, transportation policies, building energy efficiency policies, combined heat and power (CHP) technologies, and state government-led initiatives around energy efficiency, appliance, and equipment standards. Retrieved from https://www.aceee.org/

1.3.1 Structural Model

Based on the study of Solow (1956) on the growth model, the adopted structural framework for analyzing renewable energy and economic growth in this study can be simplified as:

$$Y = ARew^{\eta} \qquad 1$$

The production function includes a constant A, which accounts for other influential factors such as labor, capital, and their respective productivities. In this study, A is assumed to have one-to-one relationship with output, therefore, normalized to 1. Rew denotes the level of renewable energy, and the parameter η is defined as: $\eta = b.h$

The impact of efficiency programs and the partial contribution of renewable energy to output are represented by h, b respectively. For simplicity, the model does not include electricity prices.

The variable $h \geq 1$ represents state efforts in energy efficiency programs and renewable energy technology. The state plays a significant role in the value of h. States that mandate investors to integrate only efficient energy sources to grid systems would have a higher value of h. For example, standard interconnection rules of renewable energy and output-based emission regulations enhance the nature of energy technology deployed by private investors, and promote renewable energy (Eldridge et al., 2007). These programs streamline grid connections and motivate green and efficient energy production. Standard interconnection rules simplify the integration of distributed generation projects, such as combined heat and power (CHP) systems, while encouraging fuel efficiency. Usually, states that prioritize uniform interconnection standards facilitate the adoption of efficient energy technologies. Based on Solow's proposition that newer improved equipment outperforms the older ones, the size and the impact of h is set to increase as newer technology are deployed in generating energy. These initiatives can lead to an improved energy technology, attract clean energy investments, reduce energy costs, and further engender productivity. Therefore, as h increases, the contribution of renewable energy grows in the output-renewable relationship.

1.3.2 Empirical Model

The Rew and EnerP data show seasonal patterns, so the standardized X12 seasonality model is applied to obtain the de-seasonalized series for the two variables for all groups. The stationarity of the variables is checked using the Augmented Dickey-Fuller test, and the data series that is not stationary at I(0) is differenced. The standard reduced form VAR is represented as:

$$
\begin{aligned}
Rew_{it} &= a_{10,i} + \sum_{j=1}^{n} a_{11,ij} Rew_{it-j} + \sum_{j=1}^{n} a_{12,ij} EnerP_{it-j} + \sum_{j=1}^{n} a_{13,ij} Y_{it-j} + E_{1t} \\
EnerP_{it} &= a_{20,i} + \sum_{j=1}^{n} a_{21,ij} Rew_{it-j} + \sum_{j=1}^{n} a_{22,ij} EnerP_{it-j} + \sum_{j=1}^{n} a_{23,ij} Y_{it-j} + E_{2t} \\
Y_{it} &= a_{30,i} + \sum_{j=1}^{n} a_{31,ij} Rew_{it-j} + \sum_{j=1}^{n} a_{32,ij} EnerP_{it-j} + \sum_{j=1}^{n} a_{33,ij} Y_{it-j} + E_{3t}
\end{aligned} \tag{2}
$$

The error terms E can be expanded as follows:

$$
\begin{aligned}
E_{1t} &= \gamma_{11,i}\varepsilon_{rt} + \gamma_{12,i}\,\varepsilon_{pt} + \gamma_{13,i}\,\varepsilon_{yt} \\
E_{2t} &= \gamma_{21,i}\,\varepsilon_{rt} + \gamma_{22,i}\varepsilon_{pt} + \gamma_{23,i}\varepsilon_{yt} \\
E_{3t} &= \gamma_{31,i}\varepsilon_{i,rt} + \gamma_{32,i}\varepsilon_{i,pt} + \gamma_{33,i}\varepsilon_{i,yt}
\end{aligned} \tag{3}
$$

The state and group of states are indexed by $i = (1\!:\!m)$, where m is the number of categories depending on each classification approach. Lag terms are $j = (1\!:\!n)$, where n is the number of lags. The vector of the reduced-form parameters is represented by a'_s, and data are monthly data between 2001 and 2021. Rew_t represents the renewable generation, $EnerP_t$ represents the retail electricity price in percentage and Y_t represents the coincident economic activity index measuring economic activities. The structural shocks to renewable energy, electricity price, and economic activities are represented by $\varepsilon_{rt},\ \varepsilon_{pt}\ and\ \varepsilon_{yt}$ respectively and are assumed not to be correlated. The primary – causal –parameters of interest are the shock response, γ'_s. Renewable shocks are treated the same for all categories and generate shock responses for electricity prices and economic activities. In this study, two sets of approaches are reviewed for VAR identification: the recursive and the heteroscedasticity approach, with the former reviewed to form the foundation for the latter, which is motivated by the rising level of renewable energy generation in recent years.

1.3.3 Recursive Identification

The error terms in Equation 3 can be simplified to a vector of three exogenous shocks. Since the analysis is the same for all groups, the subscripts (i) are dropped.

$$E = \begin{pmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} \end{pmatrix} \begin{pmatrix} \varepsilon_{rt} \\ \varepsilon_{pt} \\ \varepsilon_{yt} \end{pmatrix} \qquad 4$$

Let $E = (E_1\ , E_2\ , E_3\ )$, Γ is the coefficients of the γ_{ij} and ε the vector of error term

$$E = \Gamma\varepsilon$$

$$\mathbb{E}(\mathrm{E\,E}') \equiv \mathrm{Var(E)} = \Gamma.\mathrm{Var}\,(\varepsilon).\Gamma'$$

Normalize $\gamma_{11}, \gamma_{22}\ and\ \gamma_{33} = 1$, i.e., the individual shocks' variance equals 1. The variance-covariance of the shocks of the system is given by:

$$\mathbb{E}(\mathrm{E\,E}') = \begin{bmatrix} \sigma_r{}^2 + \gamma^2{}_{12}\sigma_p{}^2 + \gamma^2{}_{13}\sigma_y{}^2 & & \\ \gamma_{21}\,\sigma_r{}^2 + \gamma_{12}\,\sigma_p{}^2 + \gamma_{13}\gamma_{23}\,\sigma_y{}^2 & \gamma^2{}_{21}\sigma_r{}^2 + \sigma_p{}^2 + \gamma^2{}_{23}\sigma_y{}^2 & \\ \gamma_{31}\,\sigma_r{}^2 + \gamma_{32}\gamma_{12}\,\sigma_p{}^2 + \gamma_{13}\,\sigma_y{}^2 & \gamma_{31}\gamma_{21}\,\sigma_r{}^2 + \gamma_{32}\,\sigma_p{}^2 + \gamma_{23}\,\sigma_y{}^2 & \gamma^2{}_{31}\sigma_r{}^2 + \gamma^2{}_{32}\sigma_p{}^2 + \sigma_y{}^2 \end{bmatrix} \quad 5$$

In Equation 5, there are nine unknowns $(\sigma_r{}^2, \sigma_p{}^2, \sigma_y{}^2, \gamma_{12}, \gamma_{13}, \gamma_{21}, \gamma_{23}, \gamma_{31}, \gamma_{32})$ and six sets of moment condition. Therefore, three parameters, γ_{12} , $\gamma_{13}\ and\ \gamma_{23}$, are subject to timing restrictions. Then, GMM numerical optimizations are used to solve for the remaining parameters, $\gamma_{21}, \gamma_{31}, \gamma_{32}$, and cumulative responses are generated for shocks to renewable generation.

Although this recursive method might be challenging to justify, given the interconnectedness between the energy market and the economy, the assumption it entails could serve practical purposes. The assumption of recursiveness is particularly relevant when considering that the growth in renewable energy is primarily driven by the declining costs of technologies, especially in wind and solar power system. In this case, renewable energy is endogenously determined by its own supply-side factors. The cost of crystalline silicon modules–a component of solar panels, and the cost of installing solar panels have dropped dramatically in the last decade. Similarly, the levelized energy costs for utility-scale renewable energy plants have declined compared to similar size of fossil fuel power plant. Hence, declining technology costs could be said to have substantially caused the surge in renewable energy production nationwide.

On the policy front, several energy regulations support renewable energy sources in many states. For example, the states of California, Texas, and Washington have implemented over 170 policies to support green energy. At the federal level, the SunShot program, established by the Solar Energy Technologies Office (SETO) of the U.S. Department of Energy, was implemented in 2011 to speed up the advancement of cost-competitive solar technologies. These energy legislations caused significant impacts on the energy mix in some states in the United States.

The increasing support for energy policies and the reduction in technology costs are key factors driving the expansion of renewable energy. With this context, it is, therefore, plausible to assume that dynamics in electricity prices are not the primary determinant of shocks in renewable generation in the short-term, $\gamma_{12} = 0$. The assumption that electricity prices have no direct impact on renewable energy shock could also be supported by the view that a minor change in electricity prices within a one-month window is not enough to cause a significant impact on renewable investment. Furthermore, while long-term economic growth can positively affect renewable energy development, short-term dynamics such as a one-month change in output will not significantly cause an increase in renewable energy. For significant effects, economic growth must be sustained over a more extended period, such as a quarter or a year. Hence, $\gamma_{13} = 0$.

The relationship between energy prices and economic growth has been explored extensively in the literature. Research indicates that while there may be a long-term connection between energy prices and economic activity, short-term fluctuations in electricity prices are primarily driven by external factors such as weather and geopolitical events, and supply dynamics (Hamilton, 2009; Kilian & Park, 2009). The proposition suggested put forward here is that economic activities do not significantly impact short-term changes in electricity prices, $\gamma_{23} = 0$.

The objective function is represented in Equation 6. The equation on the left-hand side is the matrix elements in Equation 5. The deviation from the moment conditions is estimated on an observation-by-observation basis, such that the vector with the elements in Equation 6 is computed for all elements $t = 1, \ldots, T$.

$$
\begin{array}{ccccccc}
\sigma_r^2 & + & \gamma^2{}_{12}\sigma_p^2 & + & \gamma^2{}_{13}\sigma_y^2 & = & E(\widehat{e_{rt}}\widehat{e_{rt}}') \\
\gamma_{21}\,\sigma_r^2 & + & \gamma_{12}\,\sigma_p^2 & + & \gamma_{13}\gamma_{23}\,\sigma_y^2 & = & E(\widehat{e_{rt}}\widehat{e_{pt}}') \\
\gamma^2{}_{21}\sigma_r^2 & + & \sigma_p^2 & + & \gamma^2{}_{23}\sigma_y^2 & = & E(\widehat{e_{pt}}\widehat{e_{pt}}') \\
\gamma_{31}\,\sigma_r^2 & + & \gamma_{32}\gamma_{12}\,\sigma_p^2 & + & \gamma_{13}\,\sigma_y^2 & = & E(\widehat{e_{rt}}\widehat{e_{yt}}') \\
\gamma_{31}\gamma_{21}\,\sigma_r^2 & + & \gamma_{32}\,\sigma_p^2 & + & \gamma_{23}\,\sigma_y^2 & = & E(\widehat{e_{pt}}\widehat{e_{yt}}') \\
\gamma^2{}_{31}\sigma_r^2 & + & \gamma^2{}_{32}\sigma_p^2 & + & \sigma_y^2 & = & E(\widehat{e_{yt}}\widehat{e_{yt}}')
\end{array} \tag{6}
$$

Where $\widehat{e_{kt}}$ $\{k: r, p, y\}$ is observation t residuals from the reduced form VAR and $\sigma_k{}^2$ $\{k: r, p, y\}$ and the parameter of interest, $\gamma_{21}, \gamma_{31}, \gamma_{32}$, are optimal parameter guesses.

1.3.4 Critique of Recursive Identification

The recursive assumptions discussed above impose strict constraints on the relationship between variables, which may not accurately reflect the dynamics of renewable energy markets. By assuming that electricity prices and short-term economic output do not influence renewable energy generation shocks, the model overlooks the feedback loops in the energy market, which is already a consensus in the literature (see Ocal & Aslan, 2013; Eren et al.,2019; Gyimah et al. 2022).

The argument that short-term electricity price fluctuations do not significantly affect renewable energy investment may hold under specific conditions such as mature renewable energy market, the power purchase agreements (PPAs) or high investment cost. Still, it does not extend to cases where price significantly impacts investor confidence, or a situation where subsidies and incentives increases buying power of renewable energy consumers. Furthermore, this identification discredits the influence of economic activity on electricity prices, which contradicts empirical evidence suggesting that economic growth can drive energy demand, thereby affecting prices even in the short run. For example, an increase in labor productivity can potentially lead to economic growth and increase in household and business income, which can then be used for various purchases, including renewable energy consumption. These restrictions oversimplify the dynamic interactions in energy markets, leading to potential misspecifications in the model. Based on these shortcomings, this study explores alternative methods of identification.

1.3.5 Renewable Energy Development and Heteroscedasticity in Error Variance

The following context provides insight into the potential changes in the variance of the error term.

The need to address environmental challenges and foster growth has led to the implementation of various renewable energy policies, prompting many states to launch their green initiatives. For example, from 2007 to 2021, over 20 states participated in the Renewable Standard Portfolio (RSP) program, encouraging energy companies to diversify their sources. Additionally, between 2000 and 2011, 25 states implemented energy disclosure laws requiring electricity companies to inform the public about their energy sources.

Most importantly, the drive for increased green energy and low-carbon systems came to fruition under President Obama’s administration. To lessen the impact of the 2008 financial crisis on the green sector, the U.S. government provided enormous support to renewable energy companies through tax credits and loans through the 2009 American Recovery and Reinvestment

Act (ARRA). For example, the administration passed the Renewable Energy Production Tax Credit (PTC), Investment Tax Credit (ITC) and the Department of Energy's Loan Guarantee Program. It allocated $90 billion to support clean energy programs.

In recent years, the levelized costs of renewable energy technologies – solar and wind – and the risks in renewable energy investment have declined, stimulating investment in renewable energy (Neuhoff et al., 2022). Additionally, the period after the 2008 financial crisis witnessed a significant increase in wind and solar photovoltaic energy. Therefore, this rapid shift from renewable energy provides intuition for varying error variances in the VAR model, Equation 2.

In addition, the expansion of renewable energy varies across the country, with some states starting earlier in their energy mix legislation than others. Furthermore, the number of energy policies differs between states. For instance, states such as Washington, Oregon, and Vermont are considered the "greenest" based renewable energy on their current level and future targets of renewable energy generation. On the other hand, states such as Wyoming, Alaska and Louisiana are among the least "green" based on the amount of green energy generated. Thus, since states are in different transition phases, examining the changes in renewable energy generation by their homogenous characteristic is essential.

Two factors attract the choice of the heteroskedastic approach in estimating the model. Firstly, the heteroskedastic approach imposes no assumption compared to the recursive approach. Secondly, this method accounts for changes in error term variance of renewable energy. Given the recent changes in the energy market, the heteroscedasticity-identified VAR method developed in this study provides more consistent results.

By implication, this study lends to the assumptions of the feedback hypothesis, in which renewable energy and economic growth exhibit a bi-directional relationship. This is contrary to the growth theory, by extension the recursive approach, where renewable energy unidirectionally causes changes in economic development.

1.3.6 Heteroscedasticity Identified Model

This section discusses the setup of the heteroscedasticity-identified model. First, this study uses a structural break test to examine changes in the variance of error terms in renewable energy. This study is not the first to test for a break in U.S. renewable energy data, as Ohler and Fetters (2014) found evidence of a structural break in renewable energy in 1999. Secondly, this study also subjectively divides the data into equal halves.

The traditional method for identifying unknown break dates estimates the model for all potential break dates, calculates the likelihood ratio tests (LR), and tests the maximum LR against asymptotically calculated critical values. However, this method can suffer from divergence under the null hypothesis and lower test power (Perron, 2006). To avoid this problem, Andrews (1993) proposed that the break dates must be searched within 15% and 85% of the time series dataset. This methodology is applied in Equation 7. The equation is estimated using the OLS estimator, and the null hypothesis of no break date is tested using the Wald test, the Supremum F-statistic are then compared to the study of Andrews' (1993) critical value to determine the validity of the identified break dates.

$$Rew_{it} = \beta_{10,i} + \beta_{1,i}D_{it} + \sum_{j=1}^{n} \beta_{2,ij} X_{it-j} + D_{it} * \sum_{j=1}^{n} \beta_{3,ij} X_{it-j} + \varepsilon_t \qquad 7$$

In Equation 7, $D_{it} = [0,1]$ is a dummy variable that marks the start of the break date. The index i represents the index for each category of the states, while $j = (1{:}\,n)$ represents the lag term, where n is the maximum number of lags. The vector of parameters for the model is represented by β'_s, and X is a vector of all Rew, EnerP and Y lags.

The results from the structural break tests approximately deliver the optimal date for the occurrence of transition in renewable energy generation. The information revealed from the test results provide information of break date, which is further used to estimate the shock parameters without imposing any further assumptions.

The second approach for dividing the dataset involves splitting the data into two equal halves: from 2001 to 2010 and from 2011 to 2021. This method also enables a more precise analysis of the VAR model, similar to structural break analysis, as renewable energy received wide attention after the financial crisis.

The heteroscedasticity-identified moment conditions (Equation 8) are as follows.

$$
\begin{array}{ccccccc}
{\sigma_{1r}}^2 & + & {\gamma^2}_{12}{\sigma_{1p}}^2 & + & {\gamma^2}_{13}{\sigma_{1y}}^2 & = & E(\widehat{\varepsilon_{1r}}\widehat{\varepsilon_{1r}}') \\
\gamma_{21}\,{\sigma_{1r}}^2 & + & \gamma_{12}\,{\sigma_{1p}}^2 & + & \gamma_{13}\gamma_{23}\,{\sigma_{1y}}^2 & = & E(\widehat{\varepsilon_{1r}}\widehat{\varepsilon_{1p}}') \\
{\gamma^2}_{21}{\sigma_{1r}}^2 & + & {\sigma_{1p}}^2 & + & {\gamma^2}_{23}{\sigma_{1y}}^2 & = & E(\widehat{\varepsilon_{1p}}\widehat{\varepsilon_{1p}}') \\
\gamma_{31}\,{\sigma_{1r}}^2 & + & \gamma_{32}\gamma_{12}\,{\sigma_{1p}}^2 & + & \gamma_{13}\,{\sigma_{1y}}^2 & = & E(\widehat{\varepsilon_{1r}}\widehat{\varepsilon_{1y}}') \\
\gamma_{31}\gamma_{21}\,{\sigma_{1r}}^2 & + & \gamma_{32}\,{\sigma_{1p}}^2 & + & \gamma_{23}\,{\sigma_{1y}}^2 & = & E(\widehat{\varepsilon_{1p}}\widehat{\varepsilon_{1y}}') \\
{\gamma^2}_{31}{\sigma_{1r}}^2 & + & {\gamma^2}_{32}{\sigma_{1p}}^2 & + & {\sigma_{1y}}^2 & = & E(\widehat{\varepsilon_{1y}}\widehat{\varepsilon_{1y}}') \\
{\sigma_{2r}}^2 & + & {\gamma^2}_{12}{\sigma_{2p}}^2 & + & {\gamma^2}_{13}{\sigma_{2y}}^2 & = & E(\widehat{\varepsilon_{2r}}\widehat{\varepsilon_{2r}}') \\
\gamma_{21}\,{\sigma_{2r}}^2 & + & \gamma_{12}\,{\sigma_{2p}}^2 & + & \gamma_{13}\gamma_{23}\,{\sigma_{2y}}^2 & = & E(\widehat{\varepsilon_{2r}}\widehat{\varepsilon_{2p}}') \\
{\gamma^2}_{21}{\sigma_{2r}}^2 & + & {\sigma_{2p}}^2 & + & {\gamma^2}_{23}{\sigma_{2y}}^2 & = & E(\widehat{\varepsilon_{2p}}\widehat{\varepsilon_{2p}}') \\
\gamma_{31}\,{\sigma_{2r}}^2 & + & \gamma_{32}\gamma_{12}\,{\sigma_{2p}}^2 & + & \gamma_{13}\,{\sigma_{2y}}^2 & = & E(\widehat{\varepsilon_{2r}}\widehat{\varepsilon_{2y}}') \\
\gamma_{31}\gamma_{21}\,{\sigma_{2r}}^2 & + & \gamma_{32}\,{\sigma_{2p}}^2 & + & \gamma_{23}\,{\sigma_{2y}}^2 & = & E(\widehat{\varepsilon_{2p}}\widehat{\varepsilon_{2y}}') \\
{\gamma^2}_{31}{\sigma_{2r}}^2 & + & {\gamma^2}_{32}{\sigma_{2p}}^2 & + & {\sigma_{2y}}^2 & = & E(\widehat{\varepsilon_{2y}}\widehat{\varepsilon_{2y}}')
\end{array}
\tag{8}
$$

${\sigma_{1r}}^2, {\sigma_{1p}}^2, {\sigma_{1y}}^2, {\sigma_{2r}}^2, {\sigma_{2p}}^2, {\sigma_{2y}}^2, \gamma_{12}, \gamma_{13}, \gamma_{21}, \gamma_{23}, \gamma_{31}, \gamma_{32}$ are optimal parameter guesses with no timing restriction. Where $\widehat{e_{1kt}}\ \{k: r, p, y\}$ and $\widehat{e_{2kt}}\ \{k: r, p, y\}$ are observation t residuals from the reduced form VAR before and after the break date, respectively.

1.4 Results

This paper considered grouping states based on two methodologies. This method provides a comprehensive understanding of how renewable energy impacts economic activities and electricity prices based on each state's commitment to energy efficiency and green energy. The first grouped the states by the ACEEE ranking, and the second based on the dominant political affiliation of states. This approach identifies broader patterns and trends across states with similar characteristics, such as policy adoption, energy efficiency and spendings on renewable programs. Grouping the states also helps capture similarities and differences that might not be visible when analyzing individual states alone, offering a more intermediate aggregated view of how renewable energy policies and investments influence economic outcomes. The analysis proceeds with conducting the unit test and differencing the data where the series is not stationary at level [I(0)]. The test for the structural break in renewable energy development is conducted using the model outlined in Equation 7, with a conventional 15% trimming restriction. The results are used to divide the series into two sets to perform heteroscedastic VAR estimation. Also, in other analyses reported in appendix A, the data is divided into two halves to perform the VAR estimation and observe the 2-year cumulative response. The aggregate response is imperative to address the problem of merit-order and the intermittency effects of the expansion of renewable energy (Johnson and Oliver, 2019).

1.4.1 Results of Electricity Prices to a Renewable Energy Shock Based on ACEEE Classification

Table 1:3 shows the 2-year cumulative effect of the various magnitudes of shocks on renewable energy to electricity prices across the five-level ranks of the state energy efficiency scorecard after accounting for the underlying dynamics in response within this horizon. However, it is crucial to state that the shock outcomes with structural breaks and the break date subjectively imposed yielded the same result. For the topmost performer states, ranked 1 to 10, the response of electricity prices to all the various magnitudes of shocks to renewable energy was negative, with a 1% shock causing a price to fall by 0.11%. This negative response increases with more significant shocks, reaching -1.23 % for a 10% shock.

Table 1:3 ACEEE Ranking: 24-Month Cumulative Electricity Price Response to Renewable Shocks

Shock%	Ranks 1-10	Ranks 11-20	Ranks 21-30	Ranks 31-40	Ranks 41-50
1	-0.111	-0.524	-0.003	0.075	-0.001
5	-0.612	-2.702	-0.052	0.278	-0.001
10	-1.234	-5.357	-0.114	0.533	0.001

* States ranked based on their energy efficiency performance from ACEEE's indices.

For states within the ranks of 11 to 20, the negative effect is more substantial with each marginal unit shock to renewable energy, leading to a much more significant reduction in electricity prices than those within the topmost rank. A 1% shock resulted in a 0.52% reduction in electricity prices, with the impact intensifying to a 5.36% decrease in response to a 10% shock in renewable energy.

A cursory observation may seem counterintuitive, as economic theory would suggest that states in the topmost category, with more significant investments in renewable energy and efficiency levels, should exhibit a more pronounced reduction in electricity prices. However, this outcome can be justified because several other factors, such as favorable climates, which directly impact renewable energy generation, determine the magnitude of the electricity response (Owusu *et al.,* 2016). States like Illinois, Michigan, and New Jersey consistently fall within the ranks of 11 to 20 and are favored by renewable energy policy drives.

These results show that second-tier performer states like Utah, Arizona, and Pennsylvania, where electricity prices have traditionally been low due to their reliance on inexpensive natural gas and coal, can potentially experience further reductions in electricity prices with the growing integration of renewable energy and an intensive efficiency program. With their zero marginal cost, renewables are prioritized in the dispatch order, displacing more expensive conventional sources, leading to the merit-order effect, which lowers overall electricity costs. As renewable energy production increases, the reliance on fossil fuel-based generation decreases, reducing expenses related to fuel procurement, such as natural gas and coal. This reduction in fossil fuel demand further lowers electricity prices, with these savings often passed on to consumers. Pennsylvania, for example, where natural gas has historically kept prices low, the increasing share of renewables can add to this price-reducing effect by diminishing the need for gas-fired power generation. Utah and Arizona also benefit from fewer integration costs than top-performing states like California or New York, which face higher costs due to infrastructure upgrades and regulatory measures. The state of California, for example, was an early adopter of renewable energy. At the time, the technology was relatively more expensive and less efficient than newer technologies, justifying the lower price impact of renewables in California.

It is essential to say fossil fuels, particularly natural gas, play a crucial role in mitigating the intermittency of renewable energy sources like solar and wind, which are weather-dependent. Natural gas plants, acting as flexible "peaking" or backup plants, can be quickly ramped up when renewable energy generation dips, ensuring a stable and reliable electricity supply. This balancing effect prevents electricity shortages or price spikes during low renewable energy output periods. States like Arizona and Utah, with growing renewable energy sectors and a continued reliance on natural gas and crude oil reserve, benefit from this arrangement, keeping electricity prices stable despite fluctuations in renewable energy production. In states like Maine, New Hampshire, and Hawaii, geographic and policy factors influence electricity pricing. Maine and New Hampshire, with substantial wind, biomass and solar energy production, use natural gas to stabilize prices during low wind periods, while Hawaii relies on natural gas and biofuels to manage renewable variability. States like New Jersey and Illinois combine renewable energy development with fossil-fuel-based generation policies, striking a balance that allows them to enjoy both the economic and environmental benefits of renewable energy while maintaining stable and affordable electricity prices.

Overall, the combined effect of low-cost conventional sources and the expansion of renewable energy amplifies the downward pressure on electricity prices in these states. This merit-order effect, where zero-marginal-cost renewables displace fossil fuels, assumably leads to sustained lower electricity prices in these states that fall between rank 11-20 in the ACEEE scorecard.

For states within the rank 21 to 30, we observe a much smaller negative and less dramatic responses of electricity prices to various magnitude of shocks to renewable energy, starting from -0.003% for a 1% shock and increasing to -0.11% for a 10% shock. This category falls within the mid-range in energy efficiency, potentially due to slow-paced integration into renewable energy. Some of the states which consistently fall within this category are Virginia and Nevada. Virginia depends on nuclear power and natural gas, with not a lot of renewable in energy mix. Nevada, having significant geothermal and solar resources, relies on natural gas. These factors, alongside mid-range efficiency performance, limit the potential benefits of renewable energy.

Generally, the outcome of the results observed for ranks 1 to 30 aligns with the insight on the Merit Order Effect. Renewable energy generations with a low marginal cost are first dispatched, pushing out more expensive fossil fuel-based generation, consequentially resulting in lower electricity prices at the wholesale level (Sensfuß *et al.,* 2008 & Antweiler & Muesgens, 2021). Hence, with increased renewable energy integration, electricity prices are consistently suppressed. In addition, the response outcome for combined rank 1 to 30 as observed, could be attributed to the effect of economies of large scale, where the deployment of a large-scale input on renewable energy significantly reduces electricity prices (Shimomura *et al.,* 2024). In this case, the greater the magnitude of the shock, the more noticeable the price reduction for high-ranking states in the short run.

For low-ranking states, positive effects became evident for states within the ranks of 31 to 40. A 1% shock to renewable energy increases electricity prices and becomes obvious as the shock rises to 10%. This result indicates the impact of low efficiency in energy production, which could be traceable to the higher cost of grid integration (Green & Vasilakos, 2010). In contrast, the state with the lowest ranking in energy efficiency based on the ACEEE energy efficiency scorecard, which falls within the rank 41 to 50, has the effect of the shock stabilizing around zero with a minimal positive or negative change in electricity prices. The response oscillates from -0.001 to 0.001. The situation in these states reflects minimal effort towards efficient renewable capacity or somewhat minimal dependence on renewable energy for electricity generation. Some states consistently found within this rank are Mississippi, Wyoming, South Carolina, Oklahoma, West Virginia, Alabama and North Dakota. States like Wyoming, a top coal-producing state, and West

Virginia are rich in fossil fuel resources, including coal, oil, and natural gas (Staff, 2023). Their reliance on these energy sources for electricity may explain the limited progress in renewable energy integration. While some states have abundant renewable resources — Oklahoma, for example, generates significant wind energy—state efficiency programs have played a larger role in shaping the impact of renewables on electricity prices.

Furthermore, the existing energy infrastructure in these states – lower tiers in energy efficiency — heavily invested in fossil fuel generation makes transitioning to renewable energy particularly challenging. Power plants that rely on coal, oil, or natural gas require substantial capital investments, and the associated sunk costs create a strong inertia that discourages stakeholders from pursuing new renewable projects. For example, states like Wyoming and North Dakota may possess valuable wind energy potential, yet the existing fossil fuel infrastructure often overshadows these opportunities. As investments continue to flow toward optimizing and maintaining current fossil fuel systems, the growth of renewables remains stunted, and significant capital inflow would be required to reap the benefit of renewable energy resources.

Table 1:4 Two Categories: 24-Month Cumulative Electricity Price Response to Renewable Shocks

Shock%	Ranks 1-25	Ranks 25-50
1	-0.184	0.062
5	-0.990	0.244
10	-1.987	0.473

* States ranked into 2 Categories from ACEEE's indices.

This study shows similar outcomes when comparing the results of the 2-level classification based on the ACEEE State Energy Efficiency Scorecard — Table 1:4. For instance, for 2-level classification, which generally splits states in ranks 1 to 25 and 26 to 49, as the shock size increases from 1 to 10%, the price impact on states in Rank1 to 25 becomes increasingly negative. For a 1%

shock, the effect is -0.18%. For a 10% shock, the impact further contracted prices by -1.99%. This result depicts those states with significant progress in renewable energy benefits from price reduction. States in Rank 26 to 49, the impact of shocks is initially minimally positive but increases as the shock size increases. That is, for a 1% shock on the electricity price, the effect is 0.06%, and the response becomes more significantly positive as the magnitude of the shock increases to a 10% shock. The combination of states that rank low in energy efficiency, as identified by the ACEEE Scorecard, significantly influences the overall electricity prices, especially as these states consider increasing their renewable energy capacities. States such as Montana, Nebraska, Kentucky, Indiana, Arkansas, Georgia, Oklahoma, Missouri, South Carolina, Florida, Idaho, Texas, Virginia, Ohio, Alaska, South Dakota, Alabama, West Virginia, Louisiana, Kansas, Mississippi, North Dakota, and Wyoming exhibit low energy efficiency metrics. This result is expected when combining many low energy-efficient states with a smaller group of relatively efficient ones. This inefficiency stems from outdated energy infrastructure and a firm reliance on inefficient energy technology, leading to higher operating costs and a greater vulnerability to price fluctuations in fossil fuel markets. As these low-efficiency states move toward integrating more renewable energy sources, the initial costs associated with developing and implementing renewable infrastructure can increase electricity prices. While renewables typically offer lower long-term operating costs, the transition phase often requires significant capital investment in new technologies, grid upgrades, and regulatory adjustments. The combined challenge of low efficiency and an outdated fossil fuel-based infrastructure means that these upfront costs are more heavily felt, potentially driving up electricity prices in the short term.

1.4.2 Results of Economic Activities to Renewable Energy Shock Based on ACEEE Classification

The outcome for renewable energy shock to economic activities in the scenario of break date is determined by dividing the data series into equal halves is the same as the structural break. Hence, the approaches corroborate each other, thus passing a level of credibility on the outcomes.

The outcomes (Table 1:5) of renewable energy shocks on economic activities across U.S. states grouped by their ACEEE rankings revealed that the topmost performer (Rank 1 to 10) economic activities responded positively to shock to renewable energy in crescendo as shock increases—for example, 1% shock results in a 0.17% increase in economic activities. With a 10% shock to renewable energy, economic activities rise by 0.18%, reflecting the idea that top-ranking states in renewable energy stand to benefit optimally from renewable energy due to the existing level of integration in the renewable energy sector. Ranks 11 to 20 likewise exhibit similar effects on economic activities but with a high level of impact compared with rank 1-10. 1% shock produced a slightly higher increase in economic activities within this second-tier compared with the first-tier efficiency states. The result depicts that the states in the second tier have significant room for growth in renewable energy adoption and thus experience a higher marginal benefit. Ranks 21-30 likewise reveal evidence of positive economic activities' response to various magnitudes of shock to renewable energy. However, the growth rate in economic activities for the different shock levels was relatively smaller compared with rank 11 – 20. For instance, a 1% shock results in a 0.15 % increase in economic activities, while shock magnitude of 10 units results in a 0.16 % increase, depicting a minimal response as shock increases. Only a minuscule growth was observed across all levels of shock.

Table 1:5 ACEEE Ranking: 24-Month Cumulative Economic Activity Response to Renewable Shocks

Shock%	Ranks 1-10	Ranks 11-20	Ranks 21-30	Ranks 31-40	Ranks 41-50
1	0.170	0.171	0.150	0.141	0.157
5	0.177	0.189	0.160	0.140	0.157
10	0.184	0.211	0.162	0.140	0.157

*States ranked based on their energy efficiency performance from ACEEE's indices.

The Solow-Swan growth model, introduced by Robert Solow (1956), explains the positive impact of shocks on economic activities through technological innovation, such as advancements in renewable energy technologies. In a steady-state scenario, these shocks—whether driven by supportive policy regimes, research and development, or technological advancement—can shift the economy's steady-state trajectory. The model emphasizes that an economy can experience constant growth in response to each successive shock. With continuous technological improvements, an economy can sustain a steady growth rate, as increased productivity from technological progress offsets the diminishing returns to capital.

In this light, the multiplier effect of the impact of investment in renewable energy can explain the increasing economic activities for the top-performing states, especially for ranks 1 -30. Still, the evidence of the multiplier effect was outstanding for states in ranks 11 to 20. Shocks to renewable energy could take the form of investments or increased capacity in renewables, stimulate direct job creation in clean energy sectors, and indirect job creation through the supply chain and increased consumer spending in the economy. This results in more significant overall economic activity. Furthermore, the components of the Coincident Economic Activity Index, such as employment and income, increase at a multiplier rate in response to renewable energy investments.

Since the trend for each state's index is set to match the trend for gross state product, we expect a direct implication on the output of states. The outcome of the 2-classification level, particularly for states ranked 1 to 25, corroborates this finding (Table 1:6), where the shock to renewable energy yields an increase in the percentage growth of economic activities. In this case, we observed an increased level of economic activities for states ranked 1 to 25 as the magnitude of the shock to renewable energy increased. These findings align with the previous studies. For instance, Luqman et al. (2019) found similar evidence in their research on Pakistan, where positive shocks led to increased economic growth. Similarly, Ballester & Furio (2015) obtained the same result.

Conversely, low-performing states, particularly those ranked 31 to 40 and 41 to 49 in the efficiency scorecard, show little to no change or even a small decline in economic activities in response to shocks in renewable energy. In the 31 to 40 ranks, a 1% shock to renewable energy is associated with a growth of 0.14% in economic activities. However, this growth rate stays relatively unchanged, with more significant shocks. We attribute this trend to unenthusiastic policy support and inadequate infrastructure, which is not potent enough to outperform the diminishing marginal economic returns of additional renewable energy. For the lowest-performing states (ranked 41 to 49), the increases in economic activity resulting from renewable energy shocks are minimal, indicating that they are the least developed in renewable energy development.

The stagnant growth impact of renewable energy in states ranked 31 to 49 can also be interpreted within the context of the intermittency effect of renewable energy. This effect stems from the inherent variability of renewable sources like solar and wind, resulting in fluctuating energy generation due to weather conditions and time of day. Consequently, when renewable energy output and efficiency is low, states often rely on costly traditional energy sources to meet demand, increasing energy prices. On the other hand, prices may also fall during peak renewable generation periods, creating an unpredictable market environment that hampers businesses' ability to plan and invest effectively. The consequences of this intermittency result to stagnating growth rates and returns. Hence, persistent price volatility undermines confidence of investors and businesses and leads to hesitancy in pursuing renewable energy projects. As a result, in most cases, instead of fostering sustainable economic development, the challenges posed by intermittency stifle growth and limit opportunities in these states.

States like Louisiana, South Dakota, Kansas, Mississippi, North Dakota, West Virginia, and Wyoming, which consistently rank least in supporting utility, transportation, and appliance policies over time[8] fall under the economic situation explained above. Past choices and investments like dependency on fossil fuels and low investment in efficient energy sources could lock states into suboptimal economic trajectories, impede and impair economic settings (Eitan & Hekkert, 2023). For that reason, shocks to renewable energy result in a less economic benefit because states in this category must first overcome infrastructure and policy hindrances in adopting renewable energy.

Table 1:6 Two Categories: 24-Month Cumulative Economic Activity Response to Renewable Shocks

Shock%	Ranks 1-25	Ranks 25-50
1	0.173	0.153
5	0.185	0.154
10	0.200	0.155

* States ranked into 2 Categories from ACEEE's indices.

However, by reshuffling the ranking into two classification-level from the ACEEE ranking scorecard, the outcomes for 26 to 49 produce the average of the last two ranks in the 5-level classification.

[8] 2021 to 2020 ACEEE States Energy Efficiency Scorecard

1.4.3 Results of a Shock to Renewable Energy to Economics Activities based on the Progressive Nature of the states toward Renewable Energy

Table 1:7 Political Composition: 24-Month Cumulative Economic Activity Response to Renewable Shocks

Shock%	Ranks 1-10[d]	Ranks 1-10[r]
1	0.167	0.147
5	0.174	0.148
10	0.183	0.148

* Classification based on the summary of statewide results of the 2008, 2012, 2016, and 2020 presidential elections by state: Database of States Incentives for Renewable Energy (DSIRE). https://programs.dsireusa.org/system/program
d.10 Democrats States. r.10 Republican States

Another approach adopted in this paper is classifying the states by their political affiliation and progressive renewable energy adoption. Few states are selected and grouped into progressive and conservative categories based on summary of statewide results of the 2008, 2012, 2016, and 2020 presidential elections by state sourced from Database of States Incentives for Renewable Energy (DSIRE). These are states each party have triumphed consistently in those election years. The results capture how these states respond to renewable energy shocks based on the state's historical political leanings.

The progressive states show the highest and most consistent positive responses to renewable energy shocks. Their economic activities increase steadily from 0.167% to 0.183% as renewable energy shocks rise from 1% to 10% (Table 1:7). This result reflects these states' strong renewable energy innovation, efficiency performance effort, technology adoption, and strict environmental policies. Examples include California, Washington, and New York, which have some of the country's most aggressive renewable energy portfolio standards. This finding aligns with Porter's (1991) hypothesis that environmental regulations can stimulate innovation, explaining the strong positive response of economic activities to renewable energy shocks in Democrat states.

The selected conservative states, on the other hand, show a slower and modest response to renewable energy shocks. States in this category typically have less aggressive renewable energy policies. The result of renewable energy shocks for these states shows a positive but smaller response, starting at 0.147% for a 1% shock and increasing to 0.148% for a 10% shock (Table 1:7). These states benefit from renewable energy at the initial increase but the impact of further deployment of renewable technology is discarded, leading to a slower growth trajectory vis-à-vis renewable energy expansion than more progressive states.

1.5 Conclusion

This study used monthly data from 2001 to 2021 and employed heteroscedasticity-identified Structural Vector Autoregression (SVAR) models to provide an in-depth analysis of the benefits of renewable energy, focusing on electricity price and economic activity across the U.S. Previous studies have often relied on aggregated U.S. analyses, which overlook key differences in states' unique characteristics, such as renewable energy policies, energy performance, and energy infrastructure in the states. This generalized approach fails to account for how states with strong energy efficiency and advanced renewable energy adoption might experience significantly different economic outcomes than those with low energy efficiency. In contrast to previous studies, this study employs the ACEEE State Energy Efficiency Scorecard to classify states based on their level of energy efficiency. This grouping encompasses the diverse policies and infrastructural contexts on the part of the state and facilitates a more intuitive analysis.

The result from this study reveals that the cumulative two-year impact of renewable energy shocks leads to different price reactions across the states. Top-ranked states experienced a fall electricity prices as renewable energy increases. However, the states in the second tier (rank 11-

20) experienced more electricity price reductions than other categories. This response can be attributed to complementary price support by the low-cost conventional alternative energy, which mitigate the intermittency effect of renewable energy.

Overall, this study underscores the importance of renewable energy in driving economic growth and electricity price reductions, particularly in states with favorable conditions for efficient renewable energy growth.

2 Energy-Efficient Policies, States, and Emission Inventories

2.1 Introduction

Greenhouse gases (GHG) are the primary drivers of climate change, with their consequential effects already linked to human health, plants, and environmental problems (Cassia *et al.,* 2018; du Plessis & du Plessis, 2019). Carbon dioxide (CO_2) released through human activities also accounted for the cause of the planet's atmospheric depletion. Shen et al. (2020) underscored that the global CO_2 level increased 48% above pre-industrial levels in 2019. However, in recent decades, the U.S. has seen a significant decrease in its emissions, even as global annual emissions continue to rise. Clean energy advocates have attributed the reduction in emissions to the regulations that various states have implemented to promote environmentally friendly energy.

Several states have adopted several energy policies since the wake of the millennium. Despite the number of energy programs already in place to cut down the U.S. GHG emission inventories, much is still required to achieve net-zero emissions by 2050, particularly at the state level. The state's role in cutting GHG emissions is crucial as it directly controls local energy policies, transportation, and industry, making them more effective than federal agencies in implementing region-specific energy solutions. With that being said, the experience of recent decades reveals that GHG emissions have been declining at a decreasing rate. For instance, GHG emissions reduction between 2005 and 2014 was 5.7% but decreased to 4.8% between 2014 and 2022[9]. To make matters worse, emission levels have risen in some states in the past few years. States' efforts to restore their economies to pre-COVID levels may have partially driven the increase in GHG emissions.

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[9] EPA (2024) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022. U.S. Environmental Protection Agency, EPA 430-R-24-004. https://www.epa.gov/system/files/documents/2024-04/us-ghg-inventory-2024-main-text_04-18-2024.pdf

Energy efficiency is essential in reducing GHG in the U.S. (Kutscher, 2007). Efficiency programs in the U.S. have played a role in state emission reduction goals. However, these programs' limitations are that compliance varies among states (Eldridge et al., 2007). Compliance is imperative for states to achieve emission reductions. It is no surprise that states have strengthened their energy policies by incorporating compliance studies in implementing some of their energy codes. States that have consistently conducted these studies over the past five years are primarily Progressive states (Berg et al., 2020).

Some states have made little effort to effectively implement policies that enhance energy efficiency and reduce GHG emissions. The poor enforcement of these policies might have resulted from several factors, including political resistance, inadequate funding from the state, and lack of strategic energy planning and technical training to enforce energy policy. After analyzing the patterns of U.S. energy policymaking in recent decades, Heiman and Solomon (2004) attribute the ineffectiveness of most energy policies to the broader institutional framework within which these policies are formulated and implemented. For example, the 2010 American Council for an Energy-Efficient Economy (ACEEE)[10] scorecards 2010 shows that states such as Alabama, Louisiana, and Wyoming have put minimal policy effort into promoting energy efficiency for the past 10 years compared to other states such as California and Colorado[11]. The latter states have maintained constant energy usage per capita for many years. California, the state with the most effectively enforced energy policies, has had a consistent per capita energy consumption of less than 7,000 kilowatt-hours (kWh) (Eldridge et al., 2007).

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[10] The American Council for an Energy-Efficient Economy (ACEEE) is a nonprofit research organization that designs transformative policies to reduce energy waste and address climate challenges.

[11] 10 year review of American Council for an Energy-Efficient Economy (ACEE) State Energy Efficiency Scorecard

In most cases, states that have witnessed improved energy efficiency have effectively implemented programs on energy standards and codes (Berg W et al.,2020). Among all the states, California and Massachusetts have outperformed other states in their respective regions based on broad and well-implemented energy policies and legislation. It is also instructive to know that even if all states adopt California's strict emission standards, the extent of emission reductions may vary, as the impact would depend on each state's existing policies (Arel-Bundock & Martin, 2009). If this trend continues, the states with more robust policies on energy efficiency will continue to take advantage of energy efficiency technologies and establish their role as centers for research and development (R&D) in the field, leading to more jobs created in the state (Sciortino et al., 2011). Efficient energy systems create several economic benefits, including reduced level of energy and price shocks, and sustainable rate of energy consumption.

Some states are falling short of efficient energy savings among certain demographic groups, which contributes to barriers to emission in these states. According to the American Council for an Energy-Efficient Economy (ACEEE, 2023)[12], twenty-five states have energy efficiency resource standards (ERRS) for utilities, which are required to achieve minimum energy savings for low-income people. However, only three of the twenty-five states —Massachusetts, Pennsylvania, and Washington, D.C.— have specific policies targeting underserved households. Therefore, it might be fair to hypothesize that the differences in states' capacities and commitment to enhance energy efficiency presumably explain the variation in emission quantities across the

[12] American Council for an Energy-Efficient Economy (ACEEE), Report: Most States Don't Ensure Energy Efficiency Programs Benefit Underserved (May 2023), https://www.aceee.org/press-release/2023/05/report-most-states-dont-ensure-energy-efficiency-programs-benefit-underserved.

states. The advantage of studying states is that most emission programs in the U.S. have originated from state and provincial governments (Arel-Bundock & Martin, 2009).

Furthermore, the increasing impact of GHG emissions on the socioeconomic and health of the people has gained more attention in the political discourse in recent years. It is also true that the connection between political ideologies and GHG emissions has become a prominent topic in academic spheres. The discussion centers on whether the dominant political party at the state level significantly impacts the enforcement of policies targeted at reducing GHG emissions. Although understanding the relationship between the state's political ideology and emission inventory may be challenging, the connection can be inferred based on party's position on climate change, a state's funding of efficient energy initiatives, and regulations on clean energy sources. States dominated by a political party that prioritizes environmental sustainability tend to implement policies that reduce emissions (Leinaweaver & Thomson, 2016).

Suffice it to say, within U.S. politics, Democrat-led states tend to be more progressive regarding environmental issues and are more inclined to support robust climate policies that promote less-carbon energy sources. While many Democrat-led states acknowledged the problems of increasing emissions early on, some states came after to acknowledging the connection between environmental issues and climate change (Peterson, 2001). For instance, during the latter part of the 2000s, Democrat-led states allocated more funding to climate change initiatives and energy efficiency programs than their non-Democrat-led counterparts. However, the number of policies on emission reduction was generally small in the early 2000s compared to later in the decade.

To renew U.S commitment towards reducing emission, the Democrat-led governments have pledged to bring the U.S. back into compliance with the Paris Agreement. It made a $2 trillion investment in renewable energy as part of its pro-green energy campaign (Biden, 2020). The evidence that Democrat-led government tend to favor environmental issues than Republican-led government is revealed by the counter-revocation of energy policy in the last decade. In the fall of 2019, the Trump administration revoked California's authority to set its own GHG standards, a power later reinstated by the Biden administration (The White House, 2021a).

While the federal government plays an active role in promulgating energy policies, overall, state efforts have a more significant impact in pushing the agenda of net-zero emissions. State efficiency policies are already outpacing the federal government and are increasingly seen as crucial state resource (Downs et al., 2013; Eldridge et al., 2007). Therefore, increased attention on this issue raised whether the differences in state's political ideology translate to differences in emission. Better still, as analyzed in this study, whether the share of Democratic seats in the Legislature have significant emission reductions.

According to ACEEE (2018)[13] and Bannister & Hinge (2016), energy disclosure is an energy regulation that mandates electricity companies to provide accurate information to the public about the energy sources they supply, while benchmarking includes codes that require commercial and multifamily building owners to report their energy consumption to the state or municipality. Benchmarking and energy disclosure have a combined market and socioeconomic impact in achieving emission goals (Fuerst & Warren-Myers, 2018). Energy disclosure provides the public with information about energy production and consumption, which helps minimize market failure, improve financial performance for firms, and enhance economic welfare for individuals (Delmas et al., 2010; Mihalache & Bodislav, 2019; Alsaifi et al., 2020).

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[13] American Council for an Energy-Efficient Economy (ACEEE), Home Energy Efficiency Policies: Ratings, Assessments, Labels, and Disclosure (October 2018), https://www.aceee.org/sites/default/files/pdf/topic-home-energy-assessment.pdf

These energy programs sometimes involve utility companies reporting pollution levels. For example, as part of a bill enacted by the EPA in 2009, facilities that emit greater than 25,000 metric tons of GHG emissions per year must submit reports to the EPA annually (Baker & Gahm 2010). Informational energy policies, such as disclosure, have numerous advantages. According to Kontokosta (2013), energy disclosure is one of the key policy tools that can accelerate and promote efficient energy use. Hsu (2014) asserts that accurate energy information fosters market efficiency and removes structural barriers to achieving green energy goals. Tomar (2022) found that GHG emissions declined by 7.9% following the implementation of disclosure in the U.S. Apparently, the emphasis on compulsory disclosure has yielded some useful discussion around GHG mitigation, but a consensus is still far off. The literature review section provides further information on the impact of energy disclosure.

Contributing factors to states' GHG emission inventory in the U.S. are presumably enormous. For example, industrial and agricultural processes, the level of fossil fuel combustions, the size of the energy mix, and investment have significantly accounted for the increased intensity of emissions in all the states in the U.S. (Hu *et al.,* 2019; Geng *et al.,* 2021). However, states that make extra efforts to improve their energy efficiency, implement energy policies, and provide a conducive environment for enforcing the policies can potentially mitigate the increasing carbon footprints caused by these factors (Bedsworth & Hanak, 2013; Basseches et al., 2022; Bergquist & Warshaw, 2023). That is true if, for instance, a state enforces upgrades to energy-efficient appliances, retrofits buildings with better insulation and heating systems, implements programs on congestion pricing, or expands public transit infrastructure, it can significantly reduce the amount of energy required for heating and cooling or reduce emissions from vehicles, and thereby lowering reliance on fossil fuel-burning power plants. States that work closely and encourage utility companies to adopt energy-saving programs and provide accurate information to the public can reduce the energy demand. State implementing programs that support and promote electric vehicles can also effectively lower the impact of their carbon footprint on the environment.

Before this study, the question of whether energy policy, coupled with an increase in the predominant political ideology of the state, contributes to a decrease in carbon emissions remains an open debate (as surveyed in Arel-Bundock & Martin, 2009; Selin & VanDeveer, 2011; Gross, 2020). Despite the scarcity of empirical research, as far as this study is aware, no previous work has looked at the critical impact of energy efficiency efforts and political tendencies of the state on its emission inventory in the U.S. The study of Arel-Bundock & Martin (2009) narratively researched the domestic politics and emission in the U.S. but showed no clear empirical findings on factors that determine the variations in the GHG emission profile of the states and the steps to effectively use targeted energy policies to reduce their emission footprint, regardless of political orientation.

First and forecast before getting to make questions around policy designs and implementation and their consequential impact on carbon emission reduction, there are concerns about whether energy policies ultimately impact emission reduction. Tomar (2023) reveals grounds for doubting the connection between disclosure policies and the U.S. emission profile. The study asserts that the challenges surrounding data aggregation at the firm level impose restricted demand from stakeholders at the firm level. Furthermore, the climate change conundrum involves a massive challenge with collective action, which dampens the incentives for facilities to reduce emissions and for stakeholders to mobilize. While the study showed a detailed emissions analysis, the author failed to discuss how the state's political dynamics influence the enforcement of energy efficiency programs that actualize reduced GHG emission inventories.

Therefore, this study investigates GHG emissions, considering energy efficiency policy, disclosure policy, and political landscape. In other words, this study examines the disclosure policy with cognizance of political climate and its effect on carbon emissions reduction. The reason is that states predominantly progressive in ideology are apt to pass and enforce stringent energy laws and support energy programs. While the dominant political party of the states may not directly impact the carbon emission of the states, it is hypothesized in this study that it affects how the implemented policy is enforced. Therefore, the impact of the share of Democrat seats and disclosure policy are examined on the carbon emission across the states, thus showing how dominant political ideology reinforces the effect of energy policy on the carbon emission across the states. On the other hand, state policies tracked by ACEEE to score state energy efficiency performance are also considered in this study. This policy includes utility programs, transportation policies, building codes, appliance standards, and industrial energy efficiency. This study further investigates the subcomponents of these efficiency indices on GHG emission, revealing how individual policy areas impact various components of GHG examined in the study.

To preview the contribution to the literature, this study collects panel data on emissions in the electric power industry by types (CO_2, SO_2, NO_x) as well as data on state election outcomes, represented by the proportion of Democrat seats in the House, dummy data representing disclosure policy and energy efficiency captured by six policy areas[14] highlighted in annual ACEEE scorecards. The per capita emission data of the states is differenced every election period and then regressed on the lags of the share of Democrat seats in the House, disclosure policy, and changes in energy efficiency scores. Two major reasons inform the methodological approach of this study.

[14] utility and public benefits programs and policies, transportation policies, building energy efficiency policies, combined heat and power (CHP) policies, state government–led initiatives around energy efficiency and appliance and equipment standards

First, differencing GHG emissions every election year shows how political power shifts directly impact policy changes, which are vital for carbon emission reduction—where we often see the election year usually witnessed the enactment of new policies or the reversal of existing ones, precisely policies related to energy policy and emission. Second, the approach of differencing emissions on election year lessens the noise caused by short-term factors like economic fluctuations or weather patterns, which may affect the year-over-year analysis and impact of political policy shifts on emission trends.

The outcome of the analysis of this study reveals no direct short-run relationship between emission inventory and an increasing share of Democrat seats. Still, the study shows that states with a higher share of Democrats with a disclosure policy implemented experience a reduced level of GHG emission inventory than states with a lower share of Democrat representatives. Amongst all variables used for capturing energy efficiencies of the states, the result shows clear evidence of a relationship between transportation policies and emission reduction. This means that investment on public transportation system, policy on fuel-efficient standards to promote zero-emission vehicle, smart growth critically impacts GHG emission reduction. By implication, states can potentially reduce GHG emissions with increased focus on this policy area.

The remainder of this study is as follows. Section 2 reviews the literature on GHG emissions, energy disclosure policy, and energy efficiency in the context of U.S. politics. Section 3 discusses the data and the methods. Section 4 presents and analyzes the data. Section 5 provides the conclusion of the study.

2.2 Literature Review

2.2.1 Development of Benchmarking and Disclosure Policy in the U.S. States

Several states in the U.S. have adopted different policy measures to improve energy saving and to achieve the singular objective of carbon emission reductions to align with the climate change goal. Among these policies are benchmarking and disclosure. Policies on energy disclosure and benchmarking across states and cities in the U.S. began in the early 2000s to accelerate energy efficiency, mitigate the GHG effect, and enhance energy source transparency. Implementing these policies has triggered positive effects across states as they attempt to align with the country's carbon emission objectives. Implementing the policies also sensitizes the public on energy consumption and engenders building construction competition among owners to cut carbon footprint.

Most states making giant strides in the energy benchmarking and disclosure policy are typically progressive ideologies. The state of California, one of the progressive leaders in the Democratic ideology, set a target of 100% clean energy attainment by 2045 (State of California, 2023).

California and Massachusetts lead others by implementing policies that cover some or all the commercial and residential buildings. At the same time, Alaska, Hawaii, Kansas, Maine, New Jersey, New York, South Dakota, and Washington all have benchmarking and disclosure policies on commercial buildings (Berg et al., 2020). Among these listed states, five, comprising New York, Washington, New Jersey, Hawaii, and Maine, are progressive. Thus, a possible correlation between political alignment and disclosure policy outcomes is marked.

States like Arkansas, Colorado, Massachusetts, Michigan, Minnesota, New Jersey, New York, and Virginia set policies on energy savings targets that independent state-wide program administrators must measure up to through customer energy efficiency programs. Similarly, Colorado, Massachusetts, New York, and Oregon set measurable targets for reducing vehicle miles travelled and adopted the California tailpipe emission standards. (Berg et al., 2020). Most states use California's Zero-Emission Vehicle (ZEV) program to measure their energy efficiency performance of their transportation sectors.

Table 2:1 Disclosure Policy Adoption in Key U.S. State

State	**State-wide Disclosure Policies**	**Requirement**
California	Assembly Bill 802 (2015)[15] Assembly Bill 11031[16]	AB 802 requires commercial and multifamily buildings over 50,000 square feet to report energy usage data annually. Public disclosure of energy performance data is mandated. Encourages building owners to benchmark building energy performance using the State of Minnesota B3 Benchmarking tool, which compares a building's actual energy use to expected energy use if built to code and automatically integrates with EPA Portfolio Manager to obtain an ENERGY STAR performance score and certification if desired and eligible
Washington State	Energy Benchmarking and Disclosure Law (2009)	Commercial buildings over 10,000 square feet and multifamily buildings over 20,000 square feet must report energy use to the state.
Hawaii	Act 155 (2009)[17]	Requires public buildings to report energy use and encourages energy efficiency across government-owned buildings.

[15] *AB 802 Compliance | CA | Verdani Partners*. (n.d.). Verdani-Partners. Retrieved 21 September 2024, from https://www.verdani.com/ab802-compliance

[16] State of California. Assembly Bill 1103, www.energy.ca.gov/ab1103/documents/ ab_1103_bill_20071012_chaptered.pdf.

[17] Kylie Wager, Center for Island Climate Adaptation and Policy, Climate Change Law and Policy in Hawai‘i, Briefing Sheet (2012), available at http://icap. seagrant.soest.hawaii.edu/icap-publications. UNIHI-SEAGRANT-GG-12-01

Colorado	House Bill 21-1286 (2021)[18]	Mandates energy benchmarking for commercial, public, and multifamily buildings over 50,000 square feet, with data to be disclosed publicly starting in 2024.
Oregon	House Bill 2802 (2017)[19]	Establishes energy benchmarking requirements for large commercial buildings with public disclosure of results.
Minnesota	Public Building Benchmarking Program	Minnesota mandates that energy data for large public buildings must be disclosed and publicly reported to improve energy performance.
City	City Specific	**Requirements**
New York City, New York	Local Law 84 (2009)[20]	Requires annual energy benchmarking for buildings over 25,000 square feet. The reports are disclosed to the public as part of the Greener, Greater Buildings Plan.
Chicago, Illinois	Chicago Energy Benchmarking Ordinance (2013)[21]	Commercial and municipal buildings with over 50,000 square feet are required to benchmark and publicly disclose energy performance.
Seattle, Washington	Building Energy Benchmarking and Reporting Ordinance (2010)	All commercial and multifamily buildings over 20,000 square feet are required to benchmark energy performance and disclose the data.
Washington, D.C	Clean and Affordable Energy Act (2008)	Buildings over 50,000 square feet must benchmark their energy usage and disclose the data annually.
Boston, Massachusetts	Building Energy Reporting and Disclosure Ordinance (BERDO, 2013)[22]	Buildings over 35,000 square feet must report and publicly disclose energy and water use.

[18] https://leg.colorado.gov/sites/default/files/documents/2021A/bills/2021a_1286_enr.pdf

[19] *Oregon HB2802 | 2017 | Regular Session*. (n.d.). LegiScan. Retrieved 21 September 2024, from https://legiscan.com/OR/text/HB2802/id/1496953

[20] *Benchmarking and Energy Efficiency Rating - Buildings*. (n.d.). Retrieved 21 September 2024, from https://www.nyc.gov/site/buildings/codes/benchmarking.page

[21] *Chicago Energy Benchmarking Overview*. (n.d.). Retrieved 21 September 2024, from https://www.chicago.gov/content/city/en/depts/mayor/supp_info/chicago-energy-benchmarking/ChicagoEnergyBenchmarkingOverview.html

[22] https://www.cityofboston.gov/images_documents/Signed%20Ordinance_tcm3-38217.pdf

San Francisco, California	Existing Commercial Buildings Energy Performance Ordinance (2011)[23]	Requires annual energy benchmarking for commercial buildings over 10,000 square feet.
Philadelphia, Pennsylvania	Philadelphia Building Energy Benchmarking Law (2012)[24]	Requires non-residential buildings over 50,000 square feet to benchmark energy use and publicly disclose the data.
Austin, Texas	Energy Conservation Audit and Disclosure Ordinance (ECAD, 2008)	Requires energy audits for multifamily and commercial buildings and mandates benchmarking for commercial properties.
Portland, Oregon	Energy Performance Reporting Ordinance (2015	Commercial buildings over 20,000 square feet must report and publicly disclose energy usage.
St. Louis, Missouri	Energize Denver Ordinance (2016)	Implements mandatory benchmarking and disclosure of energy use for buildings in St. Louis.
Denver, Colorado	Energize Denver Ordinance (2016)	Requires buildings over 25,000 square feet to benchmark energy use and make data available publicly
Los Angeles, California	Existing Building Energy & Water Efficiency Program (2017)	Mandates energy benchmarking for buildings over 20,000 square feet and requires periodic energy audits.
Kansas City, Missouri (2015)		Regulators require energy benchmarking and public disclosure for commercial and multifamily buildings over 100,000 square feet.
Cambridge, Massachusetts (2014)		Energy benchmarking and public disclosure are required for commercial and multifamily buildings over 25,000 square feet.

Table 2:1 contains some of the specific energy benchmarks and disclosure policies. California has been at the forefront of energy disclosure legislation among other states, with Assembly Bill 802 and Assembly Bill 1103. The legislation requires commercial and large

[23] https://uli.org/wp-content/uploads/ULI-Documents/SFenergybenchmarkingreport.pdf

[24] http://www.phillybuildingbenchmarking.com/

buildings over 50,000 square feet to disclose energy usage annually (California Energy Commission, 2023). With the legislation, building owners' transparency is encouraged to benchmark energy performance with the State of Minnesota B3 Benchmarking tool. The tool compares actual and expected energy usage depending on building codes. Similarly, Washington State's Energy Benchmarking and Disclosure Law (2009) mandates that commercial buildings over 10,000 square feet and multifamily buildings over 20,000 square feet report energy use to the state (City of Seattle, 2023).

Specific cities like New York and Chicago complement these state-wide efforts. For instance, New York City's Local Law 84, which came into effect in 2009, requires the same energy benchmarking annually for buildings attaining over 25,000 square feet, with the report disclosed publicly. Moreover, the Chicago Energy Benchmarking Ordinance 2013 mandates that commercial and residential buildings over 50,000 square feet report energy performance data (City of Chicago, 2023). Public disclosure of this data motivates building owners to improve energy efficiency, leading to reductions in energy consumption and associated carbon emissions.

Colorado also recorded massive success with House Bill 21-1286 in 2021, mandating energy benchmarking for residential and commercial buildings occupying 50,000 square feet, with public disclosure starting in 2024 (Colorado General Assembly, 2023). More local jurisdictions are very much likely to adopt these policies. Most recently, Kansas City and St. Louis, Missouri; Portland, Oregon; and Reno, Nevada, adopted benchmarking ordinances[25].

[25] For more information on how municipalities are encouraging building energy disclosure, see Ribeiro et al. (2015) and Cluett and Amann (2013).

Generally, progressive states demonstrate a more substantial commitment to GHG reduction targets than non-progressive states. This effort is reflected in their level of implementation of benchmarking and disclosure policies.

2.2.2 Disclosure Policy: Impacts, Critiques and Adoption

This section reviews the literature on disclosure policy and the criticisms against its adoption. It also examines previous studies that describe the role of U.S. politics in enforcing disclosure policy and the potential environmental benefits in the U.S.

A broad consensus is that proper market functioning leads to realizing green energy goals. Sustainable green energy and low GHG emission targets require market information to be accurate, symmetric, and easily accessible. Energy information disclosure enhances energy investment, reduces adverse selection, and accelerates energy market transformation (Hsu, 2014; Kontokosta, 2013). Allcott & Greenstone (2012) also highlighted the importance of accurate information. The authors argued that the lack of proper market information creates inefficiencies in investment due to a lack of incentives for market participants to engage in low-carbon energy enterprises. Palmer & Walls (2017) illustrated landlord-tenant problems, where landlords may hesitate to invest in low-carbon energy due to concerns about not recouping the energy investment cost. Furthermore, the lack of proper information can create credit friction between banks and energy investors and make it difficult for energy companies to access loans for green energy investment, even when the risk is low (Sanderford et al., 2015). Some energy scholars have also emphasized that the lack of adequate energy information leads to rational inattention, a condition of unawareness of consumers of the fuel efficiency of durable energy goods in the energy market (Sallee, 2015; Andor et al., 2020).

Generally, a lack of disclosure creates a barrier to market efficiency. Due to the lack of transparency in the energy market, which impedes market efficiency, some states have implemented disclosure policies and benchmarking regulations. For example, California's Energy Commission implemented a comprehensive set of rules, updated in 2016, requiring retail electricity providers to disclose information such as the specifics of their electricity products, the proportion of renewable energy, fuel mix percentages, electricity generation sources, and their environmental impact on a quarterly and annual basis.

However, the findings on disclosure and GHG emissions are not clear-cut. Some energy experts have found that the relationship between GHG emission reduction and disclosure or benchmarking is inconsistent. Some scholars have, however, ultimately attributed GHG emission reduction to predominant energy sources and uses across states, time of the day, and weather conditions in different cities than energy policies. In contrast, Downar et al. (2021) underscored that the carbon disclosure mandate reduced emissions in UK-incorporated energy companies. Therefore, the lack of consensus makes it difficult to generalize the impact of disclosure on energy efficiency and low-carbon energy consumption.

Some scholars have raised many challenges of disclosure that appear to blur its impact. For example, mandatory disclosure policies that promote building retrofitting have several constraints. One key constraint is the financial investment required for energy restructuring (Hyman, 2010). Additionally, Liu et al. (2018), Ma et al. (2012), and Salonvaara et al. (2020) argued that actualizing cost-effective and energy-efficient retrofitting options could be challenging, therefore limiting the effective passing of regulations aimed at reducing carbon emissions.

Energy regulation can also cause adverse economic ramifications. For instance, critics have argued that Boston's New Building Energy Disclosure Ordinances could have a negative impact. Studies such as Stavins et al. (2013) underscored that mandatory building labeling programs in major cities could create uncertainty about energy savings and result in a distorted distribution of assets between high- and low-efficient energy property owners. Critics of energy disclosure have also argued that these policies may not effectively promote low-carbon energy investments. In some, including Delmas & Montes-Sancho (2011), no significant correlation between disclosure and renewable energy capacity is found.

In recent years, the discussions on the policy enforcement issue have primarily centered around the willingness and ability of states to address climate change (Lim & Won, 2019; de Lucas-Santos et al., 2021). States must support, encourage, and mandate agencies in implementing and enforcing green policies to realize a low-carbon goal. It is also important to note that a congress member's stance on environmental issues can affect their election chances (Arel-Bundock & Martin, 2009).

However, enforcing energy policies can be impeded by conflicting interests. While political candidates may support progressive environmental stances, corporations that emit GHG emissions may not. These contradictory interests, ideological differences between parties, separation of powers between branches of government, and the influence of deep states have made it challenging to implement climate policy at the national level (Agrawala & Andresen, 1999). While empirical research on the correlation between voting patterns and greenhouse gas emissions is limited, studies have examined the relationship between election outcomes and other energy indices.

The study of Delmas & Montes-Sancho (2011) demonstrated a positive relationship between the presence of Democratic representatives and renewable energy capacity at the firm level. The authors also found that the percentage of Democrats in a state was a better predictor of renewable energy investment than the high league conservation voters index, which measures the number of congressmen and congresswomen who vote in support of climate change policies. Furthermore, Dumas et al. (2016) revealed that political parties competitively invest in renewable energy. Aklin & Urpelainen (2013) found that competition between pro- and anti-renewable energy positions could increase green energy investments. From the Iowa Caucus survey, Cheng et al. (2016) demonstrated that a political party that supports green energy is likelier to set renewable energy goals than a less ambitious party.

Although previous studies do not provide a firm consensus on whether disclosure policies directly contribute to GHG emissions reductions, they provide contexts this current study builds upon. This paper hypothesizes that the states' willingness, support, and commitment to energy programs and standards can potentially lead to significant differences in GHG emission reductions. The state's commitment to energy efficiency measures can also reduce GHG emissions. Therefore, this study utilizes composites of states' energy efficiency programs, captured by ACEEE scorecards, with political ideologies to study the reduction in GHG emissions. In other words, this study examines how comprehensive policy frameworks, such as transportation initiatives and building energy efficiency codes, contribute to states' emissions inventories in the U.S.

Generally, given the political landscape in the U.S., this study underscores the potential of dominant ideologies in the states in shaping the level of GHG emission inventory. States governed by parties with a strong focus on environmental concerns are likelier to adopt more stringent energy policies promoting minimal emission codes and higher energy efficiency. Hence, this study posits that political ideology on the environment, combined with robust energy programs, can be a critical factor in determining the level of GHG emissions across the U.S.

2.2.3 Review of American Council of Energy Efficiency (ACEE) major components

This study examines U.S. emission reductions through the lens of sectoral energy policies. This study evaluates how states incorporate robust measures to drive energy efficiency in the U.S. and its consequential impact on GHG emissions.

The ACEEE, through its annual State Energy Efficiency Scorecard, assesses states' efficiency performance through several policy areas and has become a critical player in promoting energy efficiency policies in many states (Young et al., 2014). These policy areas provide a holistic view of state-level performance and highlight areas for improvement. Ultimately, these policies aim to increase energy use transparency and encourage the adoption of energy-efficient technologies. Hence, this study reviews the criteria for measuring energy efficiencies in the state as reported by ACEEE and their relevance in cutting down the emission inventories.

The first component of the ACEEE components is the Utility and Public Benefits Programs and Policies. The Utility and Public Benefits program components evaluate the implication of policies on electricity and gas utilities on energy efficiency. Cappers et al. (2010) examined the effectiveness of utility-sponsored programs, revealing how state policies requiring utilities to pursue energy efficiency targets can lead to significant reductions in energy consumption. They also inferred that many states with strong standards on energy efficiency record some critical economic benefits like job creation and reduced energy bills for consumers. The ACEEE scorecard component on Utility and Public Benefits Programs and Policies evaluates states' standards on energy efficiency resources, actual energy savings, and structure to determine the state's commitment to energy efficiency.

The second component covers Transportation Policies. This component examines the state's efforts to improve vehicle efficiency, reduce vehicle miles travelled, and promote public transportation. Major indicators entail adopting zero-emission vehicle (ZEV) standards, pro-electric vehicle policies, and investments in public transport. Holian & Kahn (2015) underscored that public transit investment and infrastructural development channeled towards electric vehicles could significantly reduce greenhouse gas emissions and a state's transportation sector energy consumption. A trade-off exists between GHG emissions and air quality, fuel usage, and accompanying tax revenue. Brand (2016) considered a scenario beyond mere economic gains of reducing greenhouse gas emissions but evaluate the impact of policies on the transport energy environment system and obtained a positive effect in the case of the United Kingdom.

The third energy efficiency component is the Building Energy Efficiency Policies, which encompasses the stringency of building energy codes and incentives for energy-efficient building upgrades. This component often mandates that entities share benchmarking results with potential buyers, tenants, or government agencies. In some jurisdictions, authorities also publicize this information to create a transparent market for energy performance (Berg et al., 2020). Levine et al. (2012) have examined the importance of policy implementation in building energy efficiency. They posited that implementing and enforcing stringent building codes reduces energy use in new and existing buildings. Brounen & Kok (2011) revealed that homes with energy efficiency labels sell for higher prices than non-labeled homes. A further explanation reveals that consumers are willing to offer premium prices for energy-efficient buildings due to the ability to disclose and influence market behavior. The disclosure policy relating to Building Energy Efficiency aligns with the Principal Agent theory, where one party decides how much energy to consume; based on this theory, another pays for or benefits from that choice (Gillingham et al., 2014). For instance, the renter may decide how much energy to use, but the landlord may cover the cost of heating.

Literature examines state government-led energy efficiency initiatives - the fourth component - as models for private-sector adoption. Brown et al. (2013) highlighted how state governments can set examples for businesses and consumers by adopting high-efficiency government buildings and facilities standards. The component includes government energy-saving targets and energy efficiency requirements for state buildings. State policies mandating public building energy benchmarking correlate with energy reductions and cost savings, mainly when there is a close connection between disclosure and energy-saving targets or incentives (Palmer & Walls, 2015). To achieve the state's desire for energy, the government-led initiative on energy efficiency, state governments engage in Energy Performance Contracting (EPC) as a strategy to finance energy efficiency projects in public facilities without advanced capital costs. These contracts usually include energy savings guarantees, a fundamental milestone under this component based on ACEEE categorization and require disclosure of energy performance before and after implementation. Brown et al. (2013) in their study justified the benefits of EPCs for state governments, stressing the role of transparent energy performance data in guaranteeing the accountability of service providers and the achievement of savings targets.

The fifth ACEEE component is the Combined Heat and Power (CHP) Policies. CHP technology allows for the synchronized generation of electricity and proper heat. This component evaluates state policies and incentives that promote the deployment of CHP systems, such as tax incentives and streamlined permitting processes. The potential impact of the CHP system on improving energy efficiency, especially in industrial areas, was highlighted by Elliott & Spurr

(2015). They stipulated that states with strong policies supporting CHP deployment have seen higher uptake of this technology, leading to reduced overall energy use and lower greenhouse gas emissions. To accomplish predefined goals to promote CHP technologies, the state has rolled out several incentives that generally fall under the four major components: capital cost rebate, tax credits, low tax loans, and utility credits. Zhang et al. (2016) examined the implication of these incentives on four types of buildings, including hospitals, large offices, large hotels, and primary schools, with their finding revealing the significance of incentives in reducing the payback period.

The sixth component encompasses policies on Appliance and Efficiency Standards. This category appraises state-level appliance and equipment efficiency standards that exceed federal minimums. These standards apply to various products, including lighting, HVAC systems, and electronics. Some studies, such as Gillingham et al. (2014), have confirmed that appliance and equipment standards are among the most cost-effective energy efficiency measures. They further stressed that state-level standards that exceed the minimum federal requirements could foster the adoption of more energy-efficient products and lead to significant energy savings over time.

2.3.1 Data

This study collected data on the annual emissions from the electric power industry in the U.S.: Carbon dioxide (CO_2), Sulfur-dioxides (SO_2), and Nitrogen-oxides (NOx) measured in thousand metric tons. The study uses data from the EIA database from 2000 to 2019. The emission data are logged and differenced at the mid-term and general election to eliminate heterogeneous factors affecting greenhouse gas emissions in different states. The election period is selected because this study aims to draw inferences about emission intensity from election outcomes and disclosure.

The predictors used in this study include the ratio of Democrat representatives to the total number of representatives in a state and a dummy variable representing the presence of a disclosure policy in each state. The study collates the ratio of Democrat representatives from the U.S. Congress record, an online government database detailing elected candidate. Similarly, the study obtains disclosure variable information (Appendix Figure B.1) from DSIRE, a public tool that reports on clean energy policies.

Other predictors are states' efficiency scores. The policy areas in the ACEEE State Energy Efficiency Scorecard capture the state energy efficiency, reflecting overall state efficiency performance. Transportation Policies contribute up to 10 points, evaluating states based on energy-efficient transportation methods, such as public transit, Electric Vehicle (EV) incentives, and emissions standards. Building Energy Efficiency Policies assess the implementation and enforcement of energy-saving building codes, earning up to 8 points. State Government-Led Initiatives measure state efforts in energy efficiency programs and leadership, such as research into energy technologies and promoting energy savings across sectors, worth up to 7 points. Combined Heat and Power (CHP) Policies evaluate states' efforts in systems that generate electricity and heat through efficient sources, earning 5 points based on system installations and capacity generated. Finally, the Appliance and Equipment Standards score states on adopting stricter efficiency standards beyond federal requirements, contributing 5 points. The maximum scores for each policy vary year-to-year, so these scores are representatives of how policy areas are scored.

The energy variables used in this study add to the body of literature on energy efficiency because they provide a comprehensive and multi-dimensional assessment of the outcome variable (GHG omission) in this study. Traditional measures often focus on singular factors, such as energy consumption in specific **sectors (residential or industrial), energy intensities,** electricity consumption per capita, CO_2 emissions per unit of energy**,** building energy use intensity**, and** carbon intensity, which potentially narrows the assessments of how energy efficiency initiatives impact GHG emission. In contrast, these critical policy variables collectively address the full spectrum of energy efficiency, from utility-driven programs to government-led initiatives and appliance standards. This approach encompasses policy inputs and measurable outputs, such as investment in energy efficiency, adopting energy-saving technologies, broader infrastructure and transportation changes, and the lifecycle of energy usage in buildings.

2.3.2 Model

The baseline model introduces the disclosure policy, the ratio of Democrats, and efficiency variables to investigate GHG emission reduction.

$$In(\Delta_j Y_{i,t}) = \beta_0 + \beta_1 I_{i,t-j} + \beta_2 X_{i,t-j} + \beta_3 \Delta_j Z_{i,t-j} + \xi_{i,t} \qquad 1$$

Δ_j represents changes based on the interval of election periods, where $j = \{2, 4\}$. $Y_{i,t}$ represents emission from the electric power industry by type (CO_2, SO_2, NOx, Total). $I_{i,t-j}$,$X_{i,t-j}$ and $Z_{i,t-j}$ represents lags of the dummy representing disclosure policy and the ratio of the Democrats in each state and all changes in energy efficiency variables, respectively, while $\beta's$ indicates the corresponding impacts on emission.

The baseline model investigates if greenhouse gas emissions decline further in states that have implemented disclosure policies, have a higher share of Democratic representatives, and have improved energy efficiencies.

Furthermore, the study respecifies the model to examine whether an increase in the share of House Democrats leads to stricter disclosure policy enforcement and improved energy efficiency, which directly or indirectly causes a decline in the state's GHG emission inventories. The study investigates this relationship in two ways:

$$In(\Delta_j Y_{i,t}) = \gamma_0 + \gamma_1 I_{i,t-1} + \gamma_2 X_{i,t-j} + \gamma_3 I_{i,t-1} X_{i,t-j} + \gamma_3 \Delta_j Z_{i,t-j} + \varepsilon_{i,t} \qquad 2$$

$$In(\Delta_j Y_{i,t}) = \varphi_0 + \varphi_1 I_{i,t-j} + \varphi_2 (I^*_{i,t-j} \equiv X_{i,t-j} > 0.5) + \varphi_3 I_{i,t-j} I^*_{i,t-j} + \varphi_4 \Delta_j Z_{i,t-j} + \epsilon_{i,t} \qquad 3$$

$\Delta_j Y_{i,t}$, $I_{i,t-j}$, $X_{i,t-j}$ and $Z_{i,t-j}$ are the same as the baseline. $I^*_{i,t-j}$ is the dummy variable capturing the year states have a higher share of the Democratic House. These model specifications argue that increasing Democrat representatives push states to support and prioritize environmental sustainability policies to reduce GHG emissions.

Contrary to the baseline, the parameters of interest are γ_3 and φ_3, which captures a further decline in GHG emissions with an increase in Democrat representatives and a decrease in emissions with a higher share of Democratic representatives relative to a lower share of Democratic representatives in states that have implemented the policy. The expected sign of these parameters is negative.

Cong et al. (2020) underscored in their study that disclosure is not entirely independent, $Corr(I_{i,t-j}, \xi_{i,t}) \neq 0$. Hence, equation 1 is however specified to accommodate endogeneity in the disclosure policy. GHG emissions.

Identifying appropriate instrument(s) to eliminate the endogenous components from the disclosure variable may be challenging. However, as demonstrated in the empirical section, the proportion of Democrat representatives can serve as a suitable instrument for two reasons in this study. Firstly, a strong correlation exists between states implementing a policy and the proportion of Democrat representatives. Secondly, there is no direct short-run relationship between greenhouse gas emission intensity and the ratio of Democrat representatives, except through the disclosure policy. In simpler terms, the reasoning for using the share of Democrats as an instrument metric is that the Democratic party is known to have more progressive views and actions on environmental laws and their enforcement. Given the background, the study uses 2SLS results to conduct a robustness check for the baseline models.

This study first employs a panel Probit model to check the connection between the share of Democratic representatives and disclosure policy. Technically, Probit estimation is preferred over a linear model because the disclosure variable is a binary outcome variable, and the Probit model is free from heteroscedastic errors that can be present in a linear probability model.

$$Prob(I_{i,t} = 1) = F(X'_{i,t}\theta) \equiv \int_{-}^{X'_{i,t}\theta} \phi(z)dz \quad 4$$

$I_{i,t}$ is the dummy representing disclosure policy. $X_{i,t}$ represents the ratio of House Democrats (Dem_ratio) to the total. $F(.)$ is a standard normal Cumulative Distribution Function (CDF). $i = 1,2, \dots, n$ represents the states and $t = 1,2, \dots, T$ represents the year. θ represents the probability estimate that states will implement information policy as the ratio of Democrat increases. Dem_ratio affects policy decisions if the marginal effect of change in $X_{i,t}$ on the conditional probability that $I_{i,t} = 1$ is significant.

$$\phi(X'_{i,t}\theta) \qquad 5$$

The panel Probit equation 4 is the first stage regression. The second stage regression:

$$In(\Delta_j Y_{i,t}) = \psi_0 + \psi_1 \hat{I}_{i,t-j} + \psi_2 \Delta_j Z_{i,t-j} \ \zeta_{i,t} \qquad 6$$

$\hat{I}_{i,t-1}$ represents the predicted probability of implementing disclosure in the first stage of regression.

2.4.1 Result

This study commenced with the pre-analysis (Table 2:2) of the relationship between the share of Democrat representatives and disclosure in both 2- and 4-year election cycles. The outcome revealed that under the 4-year election cycle, a change in the share of House Democrats has a positive and statistically significant impact on disclosure policy implementation. The result shows that an increase in the unit share of Democrats leads to a 24% increase in the conditional probability of implementing a generation disclosure policy. While in 2 years election cycle, the share of a House Democrat results in an 18% increase in disclosure implementation. This outcome aligns with studies by Snyder Jr &Yousaf (2020), which discovered that policy regulations become sterner in longer election cycles since politicians have more time to demonstrate transparency initiatives before facing re-election. Hence, the more significant disclosure coefficient for a 4-year election cycle gives more room for democrats in the house to legislate transparency reforms.

Table 2:2 Disclosure Policy and House Democrats

	Disclosure	
	(4-Year Interval)	(2-Year Interval)
Demo_ratio	0.24*** (0.09)	0.18*** (0.07)
Wald P-*value*	0.012	0.012
Obs.	250	500

Note: Probit estimation between disclosure and share of House Democrats. ***, ** and * indicate significance at the 1%, 5% and 10% levels.

2.4.1 Relationship Between Emission, Disclosure Policy, Energy Efficiency Scores and House Democrats

This study carried out an OLS estimation of the baseline model examining the relationship between Emission, Disclosure Policy, Energy Efficiency Scores, and House Democrats, as presented in Table 2:3. The table summarizes the regression of outcome variables (CO_2, SO_2, NOx, and total emissions) and explanatory variables over a 4-year election period and 2-year intervals. It specifically focused on disclosure policy, Democrat ratio, and other components of policies such as transportation policies, building policies, and combined heat and power initiatives that make up the energy efficiency scorecard of the states in the U.S.

Table 2 3 Relationship Between Emission, Disclosure Policy, and House Democrats

	Emission (4-Year Interval)			
	(1)	(2)	(3)	(4)
Disclosure	-0.40*** (0.00)	-1.44*** (0.00)	-0.87*** (0.00)	-0.41*** (0.00)
Demo_ratio	0.04 (0.71)	-0.19 (0.58)	0.28 (0.12)	0.04 (0.35)
ΔTranPol.	-0.04*** (0.00)	-0.26*** (0.00)	-0.16*** (0.00)	-0.07*** (0.00)
ΔBuildPol.	0.02 (0.24)	0.03* (0.50)	0.00 (0.09)	0.02 (0.13)
ΔHeatPower	0.05*** (0.00)	0.17*** (0.00)	0.08*** (0.02)	0.05*** (0.00)

ΔGovt.Init.	-0.009 (0.49)	0.00 (0.96)	-0.03 (0.31)	-0.009 (0.74)
ΔAppEff.	-0.05 (0.33)	-0.03 (0.85)	-0.04 (0.67)	-0.04 (0.52)
Wald P-value	0.00	0.00	0.00	0.00
	Emission (2-Year Interval)			
Disclosure	-0.40*** (0.00)	-1.49*** (0.00)	-0.88*** (0.00)	-0.40*** (0.00)
Demo_ratio	0.07 (0.35)	-0.19 (0.41)	0.23 (0.12)	0.07 (0.35)
ΔTranPol.	-0.04*** (0.00)	-0.19*** (0.00)	-0.12*** (0.02)	-0.04*** (0.00)
ΔBuildPol.	0.02 (0.13)	0.05* (0.15)	0.01 (0.06)	0.02 (0.13)
ΔHeatPower	0.05*** (0.00)	0.15*** (0.00)	0.08*** (0.00)	0.05*** (0.00)
ΔGovt.Init.	0.003 (0.74)	0.03 (0.48)	-0.02 (0.38)	0.004 (0.74)
ΔAppEff.	-0.022 (0.52)	0.07 (0.50)	-0.04 (0.58)	-0.022 (0.52)
Wald P-value	0.00	0.00	0.00	0.00

Note: (1) – (4) represent the regression impact of disclosure policy, energy efficiency and the ratio of the Democrat House on CO2, SO2, NOx, and total emission, respectively. ***, ** and * indicate significance at the 1%, 5% and 10% levels.

In a 4-year election period, the outcome reveals that states with disclosure policies significantly reduce emissions compared to states without disclosure policies. This result also means GHG emission inventories decline post-disclosure implementation. States with disclosure policy have 33% $(e^{-0.40}-1)$, 76% $(e^{-1.44}-1)$, and 58% $(e^{-.87}-1)$ reduction in CO_2, SO_2, NOx emissions compared with states without disclosure policies in place at 5% significance level. Moreover, the disclosure policy results in a 34% $(e^{-.41}-1)$ reduction in total emissions. The result of the 2-year election period mirrors the outcome obtained for a 4-year election. In a 2-year election cycle, in comparison to states without disclosure policies, states with disclosure policies in place saw reductions in CO_2, SO_2, and NOx emissions of 33% $(e^{-.40}-1)$, 78% $(e^{-.49}-1)$, and 59% $(e^{-.88}-1)$ respectively at a p-value 5% statistical significance. The disclosure strategy reduces total emissions by 33% ($e^{-.40} - 1$). The outcome conforms with the DiMaggio & Powell (1983) stance on Institutional Theory, which asserted that pressures for conformity and adherence to a clear mandate, driven by public expectations, lead to positive socioeconomic outcomes, such as reduced carbon emissions. This result also aligns with the public pressure theory, which posited that firms would react to threats posed by enforced regulations, and negative public perception would drive firms to comply with pollution reduction (Lyon & Maxwell, 2011). A study conducted by Peng et al. (2023) in China aligns with this position. Their study discovered that corporate carbon performance improved with increasing government environmental information disclosure degree (GEID). Nonetheless, their analysis revealed that increased public engagement mitigated the impact of GEID on corporate carbon performance. Similarly, the study by Delmas & Montes-Sancho (2011) on the effectiveness of disclosure policies in the U.S. strongly corroborates this finding. Although their study discovered that Renewable Standards negatively impact investments in renewable capacity, their results demonstrate that publicly owned and investor-owned utilities appear to respond better to renewable regulations. Despite the contrasting outcomes demonstrated in their study, they discovered that the Mandatory Green Power Option significantly impacts all utilities installed renewable energy capacity geared towards reducing emissions.

This study obtained a non-statistically significant result for the Democrat ratio in both 4-year and 2-year election circles. This result suggests that the impact of party composition of state on emission is not evidently visible. However, it is well established that Democratic-led states are generally more proactive in advocating for and implementing stringent environmental regulations that can potentially cut down GHG emission. Therefore, while the share of Democrat may not have a direct effect on emissions, it could still influence policy direction due to the party's stance on environmental legislation.

Furthermore, this study considered the impact of the subcomponents or other covariates like transport policies, heat power, appliance efficiency, government initiative, and building policy, representing composite policy areas in the states' energy efficiency. Two of these policy areas are statistically significant. They are transportation policy (TranPol) and combined heat and power (CHP) policies (HeatPower). Under a 4-year election cycle, changes in the states' efficiency scores through transportation policies bring about a reduction in CO_2, SO_2, NOx, and total emissions by 3.92% ($e^{-0.04} - 1$), 22.8% ($e^{-0.26.} - 1$), 14.7% ($e^{-0.16} - 1$) and 6.7% ($e^{-0.07} - 1$) respectively. Over the range of efficiency scores (0 to 10), the results suggest that improving efficiency through transportation policies potentially leads to 39.2%, 228.9%, 147.9%, and 67% maximum reduction in CO_2, SO_2, NOx, and total emissions.

The outcomes from the 4-year election cycle are close to the 2-year cycle. In this case, a change in transportation policies results in reduced emissions. The change resulted in a 3.92%, 17.3%, 11.3%, and 3.9% decline in It CO_2, SO_2, NOx, and total emissions. Therefore, it implies that a more stringent policy on transport produces positive outcomes by mitigating GHG emissions across U.S. states. This outcome aligns with the sustainable transport strategy of Banister (2008), which stresses the significance of reforms in the transportation sector, with such policies covering fuel efficiency standards, emission regulations, and investment in public transportation to cut down on emissions. Whereas the federal government contributes to reducing transportation-related GHG emissions by setting national standards for light- and heavy-duty automobiles, states can champion further reduction in emissions through state transportation efficiency programs (Berg et al., 2020). Policies around transportation revolve around GHG tailpipe emissions standards, zero-emission vehicle (ZEV) mandate, electric vehicle (EV) registrations, EV fees, electric vehicle supply equipment (EVSE), high-efficiency vehicle consumer incentives, targets to reduce vehicle miles travelled (VMT), integration of transportation and land-use planning, transit funding, transit legislation, freight system efficiency goals, equitable transportation access and (New) equitable transportation electrification (Subramanian et al, 2022). As new and existing policies are being developed and strongly adopted, states implementing more of these policies tend to see improvements in their efficiency scores, which contribute to their emission reductions. For the federal government to realize the national emission target, state policymakers must enforce these energy policies.

Though still in its early stages, the heavy-duty EV market has immense potential for reducing emissions (Berg et al., 2020). California, Massachusetts, New York, Oregon, and Washington are classified as states leading in renewable energy and setting high standards for emission target. A growing number of states are also embracing California's low- and zero-emission vehicle (ZEV) rules. However, it is informative to assert that these states are progressive and are majorly Democrat-led states. These states have shown a continued focus on energy policies. They have become the top energy-efficient states due to their comprehensive efficiency programs and leadership in utility-driven energy savings. For example, based on the ACEEE State Efficiency Scorecard reports, Massachusetts ranked 4th in 2006 with 4 points in transportation policies and an overall efficiency score of 29. Still, by 2019, it ranked 1st with 8.5 points in transportation and an overall score of 44.5 points, maintaining its presence in the top 10. Similarly, California scored 4 with total of 33 points in 2006 but increased to 8.5 with the total of 43.5 points by 2019. In contrast, states like Wyoming and North Dakota consistently rank in the bottom 10 in efficiency throughout the period. Being a top state in energy efficiency policies and programs offers significant economic and environmental advantages. These states tend to experience more sustainable energy demand, lower risk of price fluctuations, reduced overall energy bills, and a decreased likelihood of energy shortages or the need for costly, environmentally damaging energy projects and significant reductions in GHG emissions (Eldridge et al., 2007). The study of Ma et al. (2021) on ultra-low emission zones (UlEZ) and air quality in London corroborates the findings in this paper, which underscored that implementing the ULEZ policy has resulted in a reduction in emissions and cleaner air.

Furthermore, the outcome of the Combined Heat Power (CHP) Initiative (HeatPower) is significant in increasing emissions both in the two and 4-year election cycle. For instance, in the 4-year interval, coefficients range from 4.88, 15.6, 7.6, and 4.88% increase in CO_2, SO_2, NOx, and total emissions under 1% significance level. This result indicates that, with an increase in policies, there tends to be an increase in the contribution of combined heat and power to emissions.

Although the result obtained for combined heat power (CHP) is counterintuitive and does not align with our priori expectation, it might reflect a short-term rebound effect where energy efficiency improvements occasionally result in a rise in consumption, hence offsetting the environmental benefits. The recovered energy from CHP systems usually satisfies the rising demand for heating or cooling and is used to produce steam for industrial operations (Berg et al., 2019). It is imperative to state that policies in this area do not outrightly impose a ban on usage but simply lay out rules for integrating the distributed generated energy. Another suggested reason for this result is that high installation costs and barriers of integration have been the major issues with CHP (Downs et al., 2013). However, this study suggests as many states starts removing the bottleneck, increasing share of CHP plants in many states potentially could reverse the relationship between CHP and emissions.

On the other hand, other subcomponents of efficiency scores, such as building energy efficiency policies, state government-led initiatives around energy efficiency, and appliance and equipment standards, are not statistically significant in causing changes in GHG emissions in either election cycle within the score of this study.

Overall, the political composition of the Democrat House shows no direct short-run consistent effects while disclosure policy and energy efficiency, through transportation policy initiatives, reduce the GHG emission inventories of the states.

2.4.2 Relationship Between Emission and House Democrats in Policy States

Table 2:4 focused on the results examining the relationship between emissions and House Democrats in policy states and transportation policies. Consequent to the result obtained above, it is reasonable to generally deduce that the predominant political party is of great importance in the impact of disclosure on GHG emissions. In contrast to the baseline model, this specification examines the improvement in the impact of disclosure on GHG emission as the share of Democrat representatives in the state increases.

Table 2:4 Relationship Between Emission and House Democrats in Policy States

	Emission (4-Year Interval)			
	(1)	(2)	(3)	(4)
Disclosure_Demo	-0.59**	-2.17***	-1.04***	-0.59***
	(0.09)	(0.00)	(0.07)	(0.00)
ΔTranPol.	-0.06***	-0.24***	-0.16***	-0.061***
	(0.00)	(0.00)	(0.00)	(0.00)
Other covariates	Yes	Yes	Yes	Yes
Wald P-value	0.00	0.01	0.98	0.00
	Emission (2-Year Interval)			
Disclosure_Demo	-0.59**	-2.19***	-1.09***	-0.59***
	(0.05)	(0.00)	(0.07)	(0.05)
ΔTranPol.	-0.04***	-0.17***	-0.11***	-0.08***
	(0.00)	(0.00)	(0.00)	(0.00)
Other covariates	Yes	Yes	Yes	Yes
Wald P-value	0.00	0.00	0.54	0.02

Note: (1) – (4) represent regression impact of disclosure interacted with the share of the Democrat House on CO2, SO2, NOx, and total emission, respectively. Covariates: Disclosure policy, energy efficiency and share of House Democrats, ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

The result empirically proves that disclosure significantly impacts GHG emissions as the proportion of House Democrats in a policy state rises. The interaction between disclosure and share of Democrat House (Disclosure_Demo) shows that states with a high share of Democrats reinforce the effect of disclosure on emissions changes. In a 4-year election cycle, states in which all representatives are Democrats or share of Democrats equal 1, the CO_2, SO_2, NOx, and total emissions decrease by about 44.57% ($e^{-0.59}-1$), 88.6% ($e^{-2.17}-1$), 64.6% ($e^{-1.04}-1$) and 44.57% ($e^{-0.59}-1$) compared to all-Republican representative states in post-disclosure. It implies that the share of Democrats in state Houses amplifies the effect of disclosure across states where disclosure policies are in force. Similarly, in a 2-year election cycle, the outcome is very much the same, with Democrat House having the same impact on CO_2 and total emission reduction.

The outcomes of these analyses support the policymakers' stance on environmental protection policy in the U.S. Studies by Kahn (2007), and Costa & Kahn (2013) also corroborate this finding, revealing that Democrat states are associated with more stringent policies aimed at ensuring a sustainable environment and lowering emissions rates. Moreover, disclosure policies, particularly in the environmental context, aim to improve transparency and accountability in reporting emissions, which aligns with the broader agenda of state environmental regulation (Bordoff & Noel, 2008). Tyson (2021), in his survey study on the openness to climate change policy in the U.S., revealed a gap in ideology between Republicans and Democrats on climate change issues. Although the issue of climate change has not always resonated strongly with some policymakers, it has consistently remained a priority in most Democrat states, which have strongly advocated for green energy programs.

The coefficient for changes in efficiency score on transportation policies (TranPol.) is negative and statistically significant, with a p-value of 0.00, indicating that more stringent transportation policies contribute significantly to emission reductions across the components of GHG.

Under a 4-year election cycle, a unit change in the score of transportation policies brings about a reduction in CO_2, SO_2, NOx, and total emissions by 5.83% $(e^{-0.06} - 1)$, 21.34% $(e^{-0.24} - 1)$, 14.79% $(e^{-0.16} - 1)$ and 5.92% $(e^{-0.061} - 1)$% respectively. A similar outcome is observed in a 2-year election cycle. In this case, a change in transportation policies results in reduced emissions. The change resulted in a 3.92%, 15.63%, 10.42%, and 7.69% decline in CO_2, SO_2, NOx, and total emissions. Wald's p-value is either zero or close to zero, signifying that the model is statistically significant and that the predictors significantly and substantially account for variations in the dependent variables.

Again, all these outcomes reveal that transportation policies are crucial for reducing emissions because, in the U.S., fossil fuel combustion made up 93% of gross CO_2 emissions in 2022, with the transportation sector being the most significant emitter[26]. By implementing effective transportation policies that promote fuel efficiency, electric vehicles, and alternative modes of transportation, a state can significantly decrease fossil fuel reliance and lower CO_2 emissions (Wang et al., 2017). Creutzig et al. (2015) also argued that transport decarbonization is central to achieving broader emissions reduction targets. Therefore, as revealed in the analysis in

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[26] EPA (2024) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022. U.S. Environmental Protection Agency, EPA 430-R-24-004. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-andsinks-1990-2022

this study, targeting energy efficiency through transportation policies has more significant potential for reducing carbon emissions than other subcomponents of policy areas. California's EV emission standards should be crucial in further reducing national emissions. If widely adopted by other states, California's updated ZEV programs would significantly improve the EVs and the automotive industry's transition to electrification of the transportation (Berg et al., 2020).

2.4.3 Relationship Between Emission, Disclosure Policy, and High House Democrats

The model in Table 2:4 is respecified to include a dummy that indicates 1 when a share of Democrats is equal or greater than 50% and zero otherwise. The essence of this is to ascertain without doubt if a larger share of Democrats in the House fundamentally drives the impact of disclosure policy on GHG emissions in the state. This model specification facilitates the comparison of emission reduction between states that are predominantly Democrats and those that have implemented disclosure policies with states with policy and have lower Democrat House or state emissions in pre-disclosure policy periods and lower Democrat House. Hence, Table 2:5 presents the relationship between emissions (CO_2, SO_2, NOx, and total emissions) predominant share of House Democrats at post-disclosure policy implementation.

Table 2:5 Relationship Between Emission, Disclosure Policy, and High House Democrats

	Emission (4-Year Interval)			
	(1)	(2)	(3)	(4)
Disclosure_Demo>0.5	-0.43***	-1.68***	-0.69***	-0.43***
	(0.00)	(0.00)	(0.00)	(0.00)
ΔTranPol.	-0.06***	-0.25***	-0.16***	-0.064***
	(0.00)	(0.00)	(0.00)	(0.00)
Other covariates	Yes	Yes	Yes	Yes
Wald P-value	0.00	0.00	0.00	0.00
	Emission (2-Year Interval)			
Disclosure_Demo>0.5	-0.40***	-1.57***	-0.70***	-0.40***
	(0.00)	(0.00)	(0.00)	(0.00)

ΔTranPol.	-0.05*** (0.00)	-0.20*** (0.00)	-0.13*** (0.00)	-0.05*** (0.00)
Obs.	600	600	600	600
Wald P-value	0.00	0.00	0.00	0.00

Note: (1) – (4) represent regression impact of disclosure policy in high Democrat House states on CO2, SO2, NOx, and total emission, respectively. Covariates: Disclosure policy and share of Democrat House, a dummy for high House Democrats***, ** and * indicate significance at the 1%, 5% and 10% levels.

Disclosure_Demo > 0.5 is an interaction term representing states where disclosure policy is in force, and the share of House Democrats exceeds 50 percent. The negative and statistically significant coefficients of this variable across all models reveal states with high Democrat states and have disclosure policy, in a 4-year election cycle, experience a reduction in CO_2, SO_2, NOx, and total emission by 34.9% $(e^{-.043} - 1)$, 81.4% $(e^{-1.68} - 1)$, 49.8% $(e^{-0.69} - 1)$, and 34.9% $(e^{-0.43} - 1)$ respectively compared with states with fewer Democrat representative members and with disclosure. Similarly, during a 2-year election cycle, a state with a share of Democrat members exceeding 50% brings about 33%, 79%, 50%, and 33% reduction in CO_2, SO_2, NOx, and total emission, respectively, compared with states with disclosure and where the share of state House members is less than 50%. There is no significant difference between the results obtained in both election cycles.

The theory of Public Choice suggests that political composition plays a significant role in shaping environmental policies. In this context, states with a high share of Democrats tend to favor stricter environmental regulations. The results corroborate this perspective, as states with more than 50% Democrats and a disclosure policy see significant reductions in emissions. Fung, Graham, et al. (2007), who discussed the perils and promise of transparency, supports these findings. Their study underscored that energy policy can deter non-compliant industries, as firms tend to reduce emissions when their practices are publicly visible. An empirical validation could be seen in California, New York, Illinois, Maryland, Massachusetts, Hawaii, and Oregon, which have high Democrat House members and, simultaneously, have implemented several stringent energy policies and have performed significantly in emission reduction.

Change in transport policy scores brings about a 5.48%, 22.89%, 11.31%, and 6.16% reduction in CO_2, SO_2, NOx, and total emission, respectively, for a 4-year election cycle. For a 2-election cycle for state House members, change in transportation policy resulted in 4.88%, 18.12%, 12%, and 4.88% reductions in CO_2, SO_2, NOx, and total emission. These outcomes show the impact is more significant in the 4-year election cycle, demonstrating that the longer the policy is implemented, the larger the results.

The second phase of this analysis in this study briefly considered the possible impact of endogeneity on the results, which can be caused by reverse causality. Endogeneity could give rise to potential distortion and inconsistency in the OLS results (Kripfganz & Kiviet, 2021). In this context, both disclosures of GHG emissions might have causal effects on each other, masking the true impact on the latter. For example, states with higher emissions may be more likely to adopt disclosure energy policies in response to environmental concerns.

Since the state's political composition does not directly impact GHG emissions, from earlier results, there is significant ground to utilize the share of Democrats as an instrument variable (IV). Therefore, the baseline model is estimated with Two-Stage Least Squares (2SLS) using a share of Democrats as an instrument.

Table 2:6 Relationship Between Emission and Disclosure Policy - *IV* Estimation

	Emission (4-Year Interval)			
	(1)	(2)	(3)	(4)
Disclosure	-0.71***	-2.54***	-1.13***	-0.71***
	(0.00)	(0.00)	(0.00)	(0.00)
ΔTranPol.	-0.05**	-0.22***	-0.15***	-0.05***

	(1)	(2)	(3)	(4)
	(0.00)	(0.00)	(0.00)	(0.00)
Wald P-value	0.00	0.03	0.00	0.00
	Emission (2-Year Interval)			
Disclosure	-0.61***	-2.23***	-1.06***	-0.60***
	(0.00)	(0.00)	(0.00)	(0.00)
ΔTranPol.	-0.03**	-0.15***	-0.10***	-0.03**
	(0.04)	(0.00)	(0.00)	(0.00)
Wald P-value	0.00	0.00	0.00	0.00

Note: (1) – (4) represent the regression impact of disclosure policy on CO2, SO2, NOx, and total emission, respectively. Instruments: Share of House Democrats. ***, ** and * indicate significance at the 1%, 5% and 10% levels

The IV results presented in Table 2:6 corroborate the findings that disclosure causes a reduction in GHG emissions. The results were statistically significant and revealed the same direction of relation with the baseline. The 2SLS results are, however, higher than the result of the OLS. In the 2-year election cycle, disclosure resulted in a 51% $(e^{-.71} - 1)$ reduction in total emission in the 4-year election cycle resulted in 45% $(e^{-.60} - 1)$. The higher results observed in the 2SLS might indicate weak identification (Keane & Neal, 2021).

2.5 Conclusion

The federal government has tightened environmental policies in recent decades through its energy policy framework. Despite these several energy regulations at the center, not all states have made significant milestones in their efforts to improve their energy efficiencies and, consequently, reduce GHG emissions of their states. However, some states, such as California and Massachusetts, have ramped up aggressive energy programs in the past two decades and have consistently been among the top tier in energy-efficient states. Compared to the low-carbon energy initiatives and programs of some states, such as North Dakota, Alabama, and Wyoming, top-ranked states have benefited from the strength of their robust policy and standards.

Although potential causes of GHG emission reduction have been studied in the literature, often focusing on single-sector policies, there is a wide disparity in consensus. It is reasonable to argue that states adopt several policies that are inherently influenced by the compositions of political ideologies on the environment to reduce GHG emissions in their states. Many states, including those at the bottom of energy policy initiatives, have historically implemented multi-sectorial energy programs to address their GHG emission footprints. These efforts include implementing and promoting policy standards that reduce GHG emissions in the transportation sector, the largest emitting sector in the U.S. However, the dominant political positions on the environment in a state have a bearing on the nature of policy adoption, the energy efficiency level of the state, commitment to alternative energy sources, and, ultimately, net-zero emission and decarbonization goals. Some states with aggressive positions have continued to be leaders in fighting climate change and have become standard setters for other states.

Therefore, this study explores the effect of disclosure policy, energy efficiency metrics computed by multi-sectoral energy policies by the American Council for an Energy-Efficient Economy (ACEEE), share of Democrat House on CO_2, SO_2, and NOx, total emissions.

First, in a 2- and 4-year election period, the outcome reveals that states with disclosure policies significantly reduce emissions compared with states with no disclosure policies for all the sources of GHG emission. This finding also means GHG emission inventories decline post-disclosure implementation or GHG emission. Moreover, this study finds that the magnitude of impact is higher in the longer election cycle and is statistically significant.

Second, the outcome of the results of the share of Democrats, proxy for the state's political affiliation, do not show a clear, direct connection with the GHG emission inventory of the states. However, the results become statistically significant after interacting with disclosure policy with the share of Democrats. The analysis uses two model specifications: one interacting with the disclosure policy in a state with a dummy variable representing a larger share of Democrats, and the other interacting with the actual share of Democrat House. The results of both analyses indicate that the more a state lean to Democrat ideology, the more significant the effects of disclosure policy on all the sources of GHG emission.

Third, this study examines which policy areas capture the overall energy efficiency of states and their impact on GHG emissions reduction in the past two decades. There are a couple of methods to determine factors that reduce the emission of a state, utilizing the multi-sectorial energy efficiency policy data computed by diverse and inclusive methodologies underscored by ACEEE in evaluating GHG emission inventories significantly stands this study out from the body of literature. The results reveal transportation efficiency policies are statistically significant in reducing all the inventories of GHG emissions. Similarly, the size of the effect using the general election cycle than the mid-term. The result shows evidence that improved transportation system policies can potentially reduce emissions.

In various model specifications adopted in the study, other subcomponents of the efficiency metrics are not statistically significant.

Although the literature on GHG emission might be enormous, this paper is the first to highlight the causal effect of multi-sector energy-efficient policies on GHG emission from different sources based on the election outcomes of the states in the U.S. Understanding the impact of these policies at an interval of election cycles show how changes in political stances on the environment can change the trajectory of emission trends of states. The evidence revealed in this study points out the state's role in reducing emissions. Given that the authority to implement specific cross-state border environmental policies remains centralized at the national level, the minimum effort required from the federal government is to collaborate with states in reducing GHG emissions.

3 Energy-Efficient Policies, States, and Emission Inventories

3.1 Introduction

In line with the global agreement to reduce carbon emissions and promote alternative energy, the U.S. has significantly increased its investments in green energy in recent years. The U.S. is the second-largest country in installed renewable energy capacity after China[27]. According to Bilgen et al. (2008), Arent et al. (2011) and Gordo et al. (2024), the drive for green energy expansion is ultimately motivated by the need to achieve energy sustainability and security, mitigate the adverse effects of carbon emissions and reduce the depletion of natural resources. Several studies have documented key factors increasing renewable energy development to include economic growth (Apergis & Danuletiu, 2014; Ntanos et al., 2018), an increase in environmental policies (Martinot et al., 2005; Bae & Yu, 2018; Adelaja et al., 2010), fiscal policy in the form of tax credit (Yoshino & Taghizadeh–Hesary, 2018; Azhgaliyeva et al., 2019), an improvement in cost-saving technology (Elia et al., 2021; Jaeger, 2021) and changes in the nominal interest rate (Chen & Lin, 2024). This study investigates the implications of a monetary policy shock on the transition to a renewable energy economy. This type of shock differs from the ones estimated by conventional methods.

The need to study the impact of monetary policy on renewable energy arises from the increasing role of financial institutions and central banks in funding the transition to a low-carbon economy. There has been growing attention on how financial institutions can contribute to the transition to a net zero emission economy since the 2015 Paris Agreement (Beltran & Uysal, 2023). The financial system is now seen as a key enabler to mitigating climate change and transition to a

[27] Statista. (2023). *Leading countries in installed renewable energy capacity worldwide in 2023*. Retrieved from https://www.statista.com/s

low-carbon economy (Battiston et al., 2021). For instance, the European Central Bank (ECB) and the Federal Reserve acknowledged the significance of climate-related financial risks in monetary policy decisions (Lagarde, 2024; Higgs et al., 2022). Moreover, financial instruments such as green bonds and targeted refinancing schemes have become central to funding renewable energy investments, thus reflecting a shift in policy focus toward sustainability (Zakari, 2022). The trend in this policy shift reflects a broader movement to building a sustainable energy economy. Investment tools like green bonds have significantly served as strategic instruments within monetary frameworks. Since 2007, the green bond market has seen remarkable growth, becoming a key driver in financing renewable energy and sustainability initiatives, with the global market rising from $18 billion in 2008 to approximately $500 billion by 2021 (World Bank, 2021). The position of Global Systemically Important Banks (G-SIBs)[28] is illustrative of the increasing attention of financial institutions on renewable energy. These banks are adjusting their business lending strategies and effectively managing risk to mitigate the climate impact of emissions. Many of these banks have committed to financing the transition to a sustainable energy economy by funding renewable energy investments and reducing loans to industries contributing to emissions. Recently, the Federal Reserve of the U.S. started asking for feedback from large financial institutions on their standards toward managing the risks posed by emissions to the climate and proposing public corporations disclose their contribution towards emissions (Beltran & Uysal, 2023).

However, despite the growing participation of financial institutions for sustainability goals, the study of the effects of monetary policies on green energy investment and the energy sector has

[28] Global Systemically Important Banks (G-SIBs): The world's largest and most interconnected financial institutions. Consists of thirty banks whose failure could disrupt the global financial system

received less attention than other factors, such as energy policies, fiscal policy, and technological changes in the U.S. Hogan (2022) claimed that renewable energy sources have a low to zero marginal cost. This perspective explains why monetary policies may have received less recognition as a factor affecting renewable energy investments in the short term. An influential study by Azhgaliyeva et al. (2018) underscored that monetary policy is necessary but not a sufficient condition for the increase in wind energy production. Although the zero marginal cost of renewable energy is valid within the context of the cost of renewable energy, the monetary policy impact on overall renewable energy investments, especially the capital cost, needs further analysis. Tradeable assets, such as energy prices, are significant in determining short-term variation in renewable energy investment, and the former has a close relationship with monetary policy.

Another argument against a monetary impact is that most renewable transactions go through an agreement. The upscale growth of the renewable energy sector requires substantial upfront investment. This heavy cost requirement for renewable infrastructure has led to the emergence of many Energy Agreements (Global Energy Report, 2024). An example of such an agreement is Energy Offtake Agreements, a contract where a buyer commits to purchase a set amount of energy or capacity from a producer under predefined terms (Tech for Net Zero, 2024)[29]. These agreements ensure financial security for renewable energy developers by securing revenue streams, shrinking investment risks, and encouraging further development of renewable energy acquired by big companies under the Energy Offtake Agreement[30]. The contracts signed under this

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[29] Tech for Net Zero. (2024). *Offtake agreements*. [Online PDF]. Retrieved from https://techfornetzero.org/wp-content/uploads/2024/06/20240613_Offtake-Agreements_TfNZ.pdf

[30] American Council on Renewable Energy (ACORE) (2024**).** In energy projects like renewable energy developments, offtake agreements often take the form of Power Purchase Agreements (PPAs). PPAs stipulate the conditions under which the energy will be sold and delivered, including details like pricing, delivery plans, and duration. Retrieved from https://acore.org/wp-content/uploads/2024/12/Bridging-Demand-and-Financing-Voluntary-Offtake-in-Clean-Energy.pdf

agreement provide stability for renewable energy production and encourage new investment in green energy.

However, monetary policy can affect renewable contract agreements, such as the Power Purchase Agreements (PPA), causing renewable energy investment to fluctuate. There are two main types of Power Purchase Agreement (PPA) contracts: the Direct PPA, which is an agreement between renewable energy generators and end-users to supply wind and solar electricity at a fixed price over a long term, and the Financial PPA, where the renewable energy developer and the buyer agree on a price transaction without the physical delivery of renewable energy (Acharya, 2022). Due to regulatory constraints and market dynamics, traditional direct PPAs have primarily been converted to financial PPAs in recent years (Tang & Zhang, 2019). This change in the PPA structure can significantly expose renewable investment to changes in monetary policies just as asset prices are exposed to monetary policy changes. Financial PPAs, for example, can be sensitive to monetary policy because they are financial transactions linked to market changes, with their value affected by interest rates.

Additionally, buyers of PPA buyers face high price risk when renewables generated fall short of the expected daily supply stipulated in the contract. In this situation, the off-takers (buyers) are forced into the spot market to fill the shortage in the supply (Peña et al., 2024). In the same vein, renewable projects can pose a risk to the suppliers if the energy generated falls short of the contracted amount**,** and the average revenue realized may fall short of the average cost. Therefore, changes in monetary policy, such as interest rates and exposure to price fluctuation, can affect the value of future payments and impact the profitability of the agreement.

Monetary policy shocks can affect financial markets and, in turn, impact the opportunities in the energy market. The Federal Reserve and central banks create shocks when implementing monetary policies. These shocks can alter financial conditions, asset prices, and interest rates. For example, the Federal Reserve's unconventional policies, such as large-scale asset purchases (LSAP), can influence the energy sector through capital investment flows, which, in turn, impact production costs and subsequently affect renewable energy infrastructure.

Furthermore, the changes in monetary policy have a significant short-term effect on various factors such as technology costs and energy market returns. Monetary policies can significantly influence investment decisions in renewable energy when energy capacity declines due to rising costs of fossil fuel technologies or when energy demands push fossil fuel prices upward. This proposition aligns with the influential paper of Paraschiv-Baute et al. (2014), which modelled energy loads from transmission system operators and energy prices. The study demonstrated that introducing renewable energies into the model, such as wind and solar, leads to a decrease in the spot price of electricity and a substitution from higher-priced to lower-priced clean energy in Germany.

In many cases, Fed's monetary stance signals the changes in economic conditions, which can stimulate demand and increase investments in renewable energy. Recently, many central banks have introduced strategic monetary policies to support low-carbon initiatives and mitigate the inflationary impact of energy supply shocks. There is a growing consensus suggesting that the European Central Bank should help de-risk the financial system by directing resources toward low-carbon assets, especially given projections that interest rates may remain above 3% for the next 30 years to support the upfront costs of renewable energy installation (Schoenmaker, D., 2023).

Indeed, the future of energy sustainability depends on the desire to grow renewable energy capacity continuously. While there are financial risks and other challenges, such as the variability in weather patterns affecting the growth in renewable energy, expansionary monetary policy can accelerate large-scale investments and mitigate risks in the green energy sector.

Literature reveals no clear consensus on the impact of monetary policy on renewable energy, as various studies present differing and often contradictory findings. For instance, Chen & Lin (2024) and He et al. (2019) underscored that monetary policy loosening promotes renewable energy production. In contrast, Sun et al. (2022) and Jin et al. (2023) found that expansionary monetary policy undermines renewable energy generation in the U.S. Battiston et al. (2021) also posited that the financial system, in the pursuit of a low-carbon economy, can generate moral hazard because of the inherent risk in the renewable energy industry. The variations in methods used to capture monetary changes create a lack of consensus, as different approaches yield different insights into their effects on renewable energy. While most previous studies have used indicators such as money supply, financial subsidies, nominal interest rates, and loans to track changes in renewable energy, there is a potential drawback to the impact created by these predictable monetary measures. Interest rate movements around announcements often conflate policy shocks with central bank information, making it challenging to isolate the effects of pure monetary policy changes (Nunes et al., 2022). Therefore, the shocks measured with nominal interest rates can introduce bias to the impact on energy investment if markets react to the central bank's forward guidance before actual changes to the interest rate.

Furthermore, identifying shocks can pose empirical challenges to studying the relationship between monetary policy and renewable energy. The common approach used in the recent literature for capturing the behavior of the U.S Federal Reserve is the high-frequency bond and Fed fund futures analysis to capture interest rate fluctuations around Federal Open Market Committee (FOMC) announcements (see, Beechey & Wright, 2009; Rosa, 2014; Gertler & Karadi, 2015). Researchers have also used various econometric methods to examine the impacts of monetary policy shocks on renewable energy investment. This approach includes the Dynamic Stochastic General Equilibrium (DSGE) model, employed by Shobande & Shodipe (2019) and Razmi et al. (2021); recursive Vector Autoregression (VAR), applied by Bagliano & Favero (1999), Pellegrino (2021), and Chen and Lin (2024). There are, however, limitations to these shock estimation methods as underscored in the literature: VAR shocks lack specificity and are deficient with the introduction of new financial variables into the model (Gertler & Karadi, 2015); the representative agent assumptions, which link the interest rate to the consumer discount rate, fails to account for the zero lower bounds in DSGE estimation (Gali, 2017) and high-frequency interest rate-based shocks are highly predictable, as monetary policy announcements convey substantial macroeconomic information (Bu et al., 2021).

This study adopts a more straightforward approach than previous studies on VAR, DSGE, and high-frequency rates by utilizing the unified shock series (BRW) from Bu et al. (2021). The BRW shocks are estimated using Fama-MacBeth regressions on zero-coupon yields and based on the assumption of perfect correlation between the 2-year Treasury yield and monetary shocks. This method is appealing due to the informativeness and unpredictability of the shocks. The BRW series effectively removes the Fed's informational effects from the policy announcement and provides a cleaner and more exogenous measure of unanticipated monetary shocks that impact renewable energy investments. Additionally, the study uses the heteroskedasticity-based estimator proposed by Rigobon & Sack (2003, 2004). Furthermore, the study ensures that shocks are free from confounding macroeconomic news, making the measure particularly robust.

This study examines the impacts of monetary policy on renewable energy capacity. Using the BRW series to proxy monetary shock makes this study unique. First, it allows this study to capture the effects of monetary policy on renewables in a less traditional way. Second, as practical feedback to the BRW monetary shock series authors.

In summary, this study finds clear evidence of the impact of monetary shocks on total renewable energy capacity. This result reveals an average of 0.095% increase in the likelihood of a variation in total renewable energy capacity from a 10-basis point increase in interest rates. However, the study did not find a statistically significant relationship between monetary shocks and wind and solar energy.

3.2 Literature Review

The substantial investment required for renewable energy has led to continuous integration between the energy industry and financial markets and an increase in the participation of stakeholders (Gordo et al., 2024). With the interplay of critical financial market factors, prices of and cost of renewable energies have been impacted. Gordo et al. (2024) assert that monetary policy remains one of the tools to stimulate the desired changes in the financial market and consequently impacts changes in renewable energy capacity. The common consensus is that expansionary monetary policy, through Quantitative Easing (QE) and reduced interest rates, boost economic activity by making loans more affordable for investors and companies, thereby driving investments in the broader stock markets. One of the pioneering renewable energy papers, Henriques & Sadorsky (2008), empirically demonstrated a strong relationship between renewable energy prices, interest rates, and the stock prices of technology companies.

Rosas (2024) explores the impact of monetary policy shocks on commodity prices, especially those linked to energy inputs in the power sector, emphasizing the crucial implications for the direction of monetary policy in shaping carbon emissions within the energy sector and the broader economy. The results demonstrated in the paper show that monetary policy responses to commodity prices impact electricity generation costs. For example, the study shows that changes in monetary policy often drive the energy sector towards less carbon-compliant, lower-cost fuels and displace cleaner for costlier alternatives such as natural gas in the short term. Fornaro et al. (2024) examined the trade-offs between renewable energy capacity and inflation. Their study argues that contractionary monetary policy reduces inflationary pressures in the short term but dampens renewable energy investment due to higher interest rates, leading to increased capital costs and reduced demand for clean energy. Ultimately, an increase in the interest rate slows productivity growth in the clean sector. Hawkish monetary policy can heighten the investment costs of renewable energy infrastructure. Although contractionary policy may curtail inflation briefly, it causes persistent economic losses for renewable energy (Fornaro & Wolf, 2023). However, Shah et al. (2018) highlighted oil prices as a significant determinant of renewable energy investment and production, although their views vary on the effects depending on the magnitude of oil price fluctuations.

Money supply affects renewable energy production through its impact on investment. An increase in money supply enhances banks' lending capacity, thus encouraging investment and output (Sargent, 2009). Rehman (2014) & Faia (2009) argued that a monetary contraction reduces banks' reserves, limits loans to investors and leads to an output decline in all sectors. While more investors often shift to the stock market to fund investments when interest rates rise, small-scale investors without access to stock markets face stifled investment (Karanassou & Sala, 2010). This proposition aligns with Tobin's theory (Taylor, 2000), suggesting that firms will make investments when their expected future profits exceed replacement costs. Indeed, interest rate fluctuations affect investment in all sectors of the economy, including renewable energy. Haratian et al. (2018) also emphasize that real interest rates are critical in shaping the renewable energy industry.

There is broad consensus that the outcome of the FOMC meetings poses a shock to the economy and dynamically affects the financial market, which, in turn, affects the energy market. As new information arrives in the market, asset prices fluctuate after the FOMC meetings, and the market forces lead the investors to adjust their investment portfolios. The volatility arising from the FOMC announcements significantly causes financial investors to reevaluate investment decisions (Nikkinen & Sahlström, 2004). Using high-frequency fed fund rate, LSAP, and future path of policy data, Rosa (2014) demonstrated that a one-percent rise in monetary shock leads to a three-percent decrease in West Texas Intermediate oil price. The author also underscored that FOMC announcements significantly contribute to fluctuations in the volumes of crude oil futures.

The impact of the FOMC announcements on energy prices was also studied by Basistha & Kurov (2015). They found that energy prices respond significantly to changes in interest rates around the window of the monetary policy announcement. Using GARCH-MIDAS to model high-frequency energy price data, Razmi et al. (2020) assert that monetary uncertainties cause fluctuation in energy prices. Yoshino & Taghizadeh–Hesary (2018) also argued that the period of quantitative easing between 2009 and 2012 resulted in higher energy prices and increased investment in the oil market.

Ramzi et al. (2021) investigated the impact of monetary policy on renewable energy generation in Iran, focusing on different renewable sources, including biogas, hydropower, solar, and wind energy. Using Kalman filter and vector autoregression (VAR) models on 32 years of data, the study demonstrated that only shocks to the money supply impacted renewable energy generation.

Similarly, the study of Gordo et al. (2024) examined the relationship between monetary policy and renewable energy investment in the European Union (EU) in the context of Quantitative Easing (QE). Their study adopted the VAR model, Granger causality tests, impulse response functions, and the structural break analysis with a further analysis of the impact of interest rates on renewable energy stock prices, oil prices, and technology. Their result revealed that monetary policy had minimal effects on renewable energy stocks. The structural break analysis showed that specific types of monetary policy could significantly impact renewable energy stocks during key QE periods.

Castelnuovo et al. (2024) focused on the effects of monetary tightening on fossil fuels, particularly coal and natural gas. Their findings revealed that monetary policy tightening led to lower coal prices due to incentives for immediate extraction. However, the study showed a less pronounced impact on natural gas extraction. They found that temporary inflation is a natural outcome of reallocating investment toward cleaner energy. The authors asserted that a strict emphasis on price stability could lead to sustained output losses, and tight credit conditions were shown to hinder innovation, particularly in green technologies. Their result parallels the findings of Fornaro et al. (2024), which examined monetary policy trade-offs during the green energy transition using a New-Keynesian model.

Shah et al. (2018) analyzed the relationship between renewable energy investment, oil prices, GDP, and interest rates across Norway, the UK, and the USA, using a time series approach. Their results showed a strong relationship between oil prices and renewable energy investment in the USA and Norway but not the UK. The authors concluded that renewable energy investment would be sensitive to macroeconomic conditions and fossil fuel prices in countries with limited government support for renewables.

On the other hand, there are several studies on the relationship between clean and non-clean energy prices and the growth of renewable energy. For example, Managi & Okimoto (2013) and Dawar et al. (2021) found a positive relationship between fossil fuel prices and clean energy prices, while Sadorsky (2012) demonstrated a dynamic conditional correlation between oil prices and clean energy stock prices. Tambari & Failler (2020) and Murshed & Tanha (2021) reveal the direct positive impact of crude oil on renewable energy, and Li and Leung (2021) demonstrated that the rising fossil fuel cost leads to a transition to a cheaper and more sustainable energy source. Utilizing panel data from twenty-one OECD countries, Nilsson (2019) found that oil price fluctuations significantly caused an increase in renewable energy patents between 1990 and 2015. Huisman et al. (2013) show evidence of a causal relationship between the reservoir levels of hydro capacity and power prices.

In summary, the literature on monetary policy and renewable energy reveals diverse findings: DSGE models (e.g., Shobande & Shodipe, 2019; Argentiero et al., 2017, 2018) show that monetary shocks and subsidies influence renewable energy fluctuations and growth. VAR studies (e.g., Razmi et al., 2021; Nga, 2021) linked tight policies to a decline in renewable energy. Sohail et al. (2021) demonstrated asymmetric impacts of policy uncertainty on renewable energy, while Sun et al. (2022) found that expansionary policy reduces renewable energy in G7 nations. Azhgaliyeva et al. (2019) argued that loans boost green investments, but their earlier work Azhgaliyeva et al. (2018) found no link to wind production across 116 countries.

Using conventional monetary policy indicators to predict changes in renewable energy would provide little insight into the renewable energy sector. Money supply, nominal interest rates, quantitative easing, loans, and other financial instruments are predictable indices and capture a less significant portion of monetary shock, especially during periods of the ZLB in the U.S. Under near-zero interest rates, monetary policy no longer significantly impacts the renewable energy sector (Gordo et al., 2024). For a monetary policy shock to be unpredictable, it must effectively link periods of conventional and unconventional monetary policymaking and be devoid of the Fed's information effect (Bu et al., 2021). As revealed in past literature, most central bank policies contain decarbonization goals. Therefore, measuring the causal impact of monetary shocks on renewable energy requires that these shocks be unanticipated. This paper deviates from previous studies examining the effect of monetary policy on renewable energy by focusing on the connection between changes in the installed capacity of different renewable energy sources and unanticipated monetary shocks.

On the other hand, this study contributes to the literature by emphasizing the importance of examining renewable energy capacity rather than focusing on production, consumption or generation when analyzing the effects of monetary shocks on the renewable energy sector. Although previous studies, such as Chen & Lin (2024), Razmi et al. (2021) and Nga (2021), that concentrated on renewable energy production or generation may have arrived at a similar conclusion to this study, monetary policy affects renewable energy investment rather than the production of renewable energy. Weather conditions significantly affect the level of renewable energy generated, produced and consumed, which makes it difficult to isolate the causal impact of monetary policy shocks on the changes in renewable energy. While the capacity of existing renewable energy technologies determines clean energy supply, climatic variations, such as wind speed and solar radiation, continuously influence the actual energy output.

3.3 Data and Method

This study examines the impact of monetary shocks on changes in renewable energy capacity. The dependent variable—state-level net summer capacities of renewable energy (RC) — reflects structural investment decisions and changes less frequently. To focus on how monetary policy shocks cause changes in renewable investment, RC is transformed into a binary variable (RC=1 for a change in installed capacity, RC=0 otherwise) each month. This variable transformation makes it easier to estimate the causal effects of policy changes on renewable energy. However, while this transformation obscures the magnitude of the impact of monetary shocks on renewable energy, this study focuses on determining whether monetary shocks influence renewable energy investment. This method is distinct from previous studies that examine renewable energy generation and production, which are significantly impacted by the weather conditions throughout the year. Therefore, this approach of transforming RC to a binary sequence avoids noise from weather-related factors. Specifically, this method demonstrates a more unambiguous identification of the causal relationship between monetary policy and renewable energy investment.

The independent variable is the monthly Bu, Rogers, and Wu (BRW) shock series (Rate_shock) between 2014 and 2020, estimated by Bu et al. (2021). The monthly BRW shock series is suitable for this analysis because it potentially captures pure monetary shocks devoid of Fed information effect and macroeconomic conditions. Unlike the traditional monetary policy indicators — interest rates, money supply, QE, and conventional methods for estimating monetary policy shocks, which are often anticipated by markets and influenced by macroeconomic conditions — the BRW series focuses on unanticipated changes in monetary policy[31].

An increase in the marginal costs of renewable power generation can increase power prices (Huisman et al., 2013). Therefore, the estimation control for several variables, including Natural Gas City and NYMEX-traded Cushing dollar per thousand-cubit (NatGas_Price), electricity price in cents per kilowatt (Electric_Price), Oklahoma Crude oil futures per barrel (Crude_Price), total renewable energy consumption by sources (*_RewCons), where * = [Tot, Hy, Bio, Solar, Wind]. The models are controlled for weather impact using the cooling days (cool) index, where cool =1 if the monthly average changes and cool=0, otherwise. Cooling day is a quantitative index that indicates the demand for energy to cool houses and businesses. The model also includes the interaction of cooling day and renewable energy consumption by source (*_RewCons_Cool). All energy prices are controlled for inflation.

This study employs a Probit model for analysis but acknowledges the potential feedback causality between renewable energy investment, energy price changes, and renewable energy consumption. Krozer (2013) and Elia et al. (2021) earlier reported interdependence between energy prices and renewable energy. Therefore, an IV Probit model is also used for robustness checks.

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[31] The authors provided an online appendix at the Finance and Economics Discussion Series to replicate the shock series:
https://www.federalreserve.gov/pubs/feds/2006/200628/200628abs.html,
https://www.federalreserve.gov/econres/feds/a-unified-measure-of-fed-monetary-policy-shocks.htm

The instruments used in this study are the average costs of fossil fuels (petroleum and natural gas) used in electricity generation, stock of fossil fuels in electric power sectors, total emission, and total industrial production index. Although these instruments may not be strongly exogenous, they strongly correlate with energy prices and renewable energy consumption.

All the energy data used in this study were obtained from the Energy Information Administration (EIA) from 2014 to 2020, and the monetary policy shock series was sourced from the Board of Governors of the Federal Reserve System.

The following equations illustrate the econometric models.

$$RC_{i,t} = \beta_0 + \beta_1 MS_{i,t-1} + \beta_s X^s{}_{i,t-1} + \xi_{i,t} \qquad 1$$

$i = 1,2,\dots,n$ represents the states and $t = 1,2,\dots,T$. $RC_{i,t}$ is a dummy variable representing changes in the installed capacity for each energy source. $MS_{i,t-1}$ is the lag of monetary policy shocks, and the subscript (*i*) is trivial as *M.S.* is time-series data. $X^s{}_{i,t-1}$ is the vector of lags of logged other covariates.

The parameter of interest, β_1, represents the marginal effect of monetary shocks on the renewable energy capacity— a value at $\beta_1 < 0$ indicates that loosening monetary policy increases the likelihood of changes in renewable energy capacity. That is, expansionary monetary policies encourage investments in renewable energy infrastructures. $\beta_1 > 0$ shows that expansionary monetary shocks decrease the likelihood of a change in renewable energy capacity (Sun et al. 2022; Jin et al. 2023). As it is unlikely to disinvest the renewable energy infrastructure, changes in this context mean an increase in renewable energy capacity. Disinvestment in renewable energy infrastructure is rare due to high barriers such as significant sunk costs and regulatory hurdles. It is more common to increase, rather than reduce, existing capacity. Given the long-term renewable energy sustainability goals and the policy support, the state's focus is to increase capacity, repurpose or upgrade existing infrastructure rather than disinvestment.

Values for β_s represent the marginal effects of the covariates. The expected sign for renewable consumption is positive, and the expected signs for energy prices are unknown, a priori. Although economic principles suggest that the sign of energy prices should be positive, studies have shown different results. Since low-carbon energy infrastructure relies heavily on fossil fuels, the relationship between renewables and oil prices can be negative (see Tsai et al., 2016; Dominioni et al., 2019).

The panel Probit estimation of the econometric model:

$$Z = \left(MS_{i,t-1}\, X^{s}{}_{i,t-1}\right)$$

$$Prob\left(RC_{i,t} = 1\right) = F\left(Z'{}_{i,t}\theta\right) \equiv \int_{-}^{Z'{}_{i,t}\theta} \phi(w)\, dw \qquad 2$$

$F(.)$ is a standard normal Cumulative Distribution Function. The vector Z includes independent variables. The marginal effects for a change in $Z'{}_{i,t}$ on the conditional probability that $RC_{i,t} = 1$:

$$\phi\left(Z'{}_{i,t}\theta\right) \qquad 3$$

Primarily, the parameter of interest, β_1, should be less affected due to the possibility of endogeneity $Corr\left(X^{s}{}_{i,t-j}, \xi_{\ i,t}\right) \neq 0$, this study conducts a robustness check using an IV Probit model.

The first stage model for the covariates is as follows.

$$X^{s}{}_{i,t} = \alpha_0 + \alpha_k z'{}_{i,t-1} + \epsilon_{i,t} \qquad 4$$

$X_{i,t}$ is the individual covariate and $z'{}_{i,t-1}$ is the vector of selected instruments, where $Corr(z'{}_{i,t-j}, \epsilon_{i,t}) = 0$.

The second stage of the econometric model is as follows.

$$RC_{i,t} = \gamma_0 + \gamma_1 MS_{i,t-1} + \gamma_s \hat{X}^{s}{}_{i,t-1} + \zeta_{i,t} \qquad 5$$

$\hat{X}^{s}{}_{i,t-1}$ is the lag of the predicted series from the first stage, where $corr(\hat{X}^{s}{}_{i,t-1}, \zeta_{i,t}) = 0$.

3.4Results

Monetary policy shocks in the U.S. occur when the Fed announces its future monetary actions to stimulate the economy towards a desired outcome. Based on this announcement, the market interest rate rises, declines, or remains unchanged. This study examines the fluctuations in the monetary policy around the FOMC meetings with the BRW shock series in Fig. 1[32]. The shocks are measured in percentages. The region above the zero point in the plot indicates a contractionary policy shock, and the region below the zero point is an expansionary policy shock. The shock series offers significant insight into the Fed's policy actions during the periods. For example, the

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[32] The shocks series was estimated by Bu et al. (2021) and sourced from the Finance and Economics Discussion Series (FEDS)

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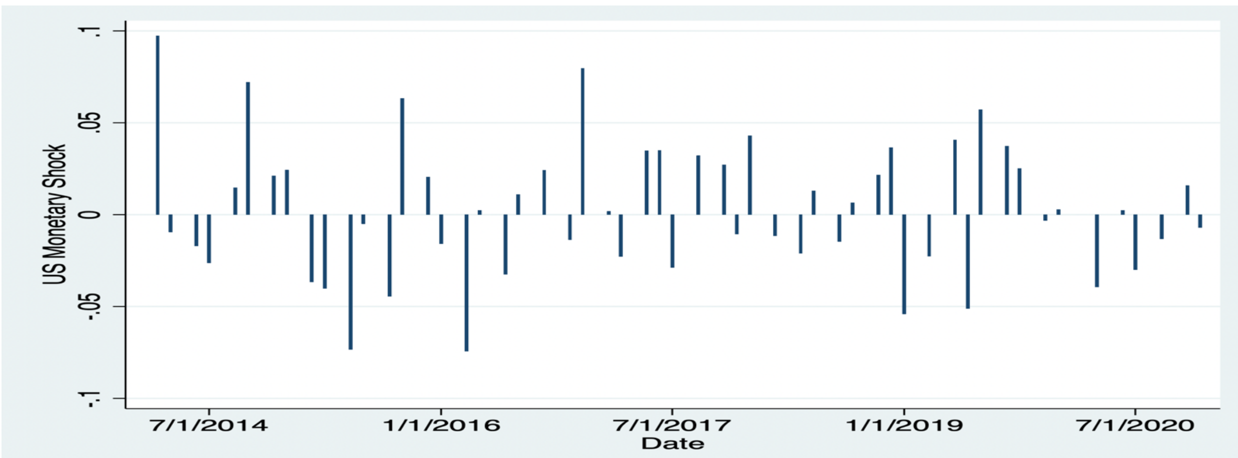
positive BRW shock series reflected the hawkish policy of the Fed in mid-December 2017 aimed at stabilizing inflation and economic growth. Similarly, consistent with the Fed's forward guidance in the 4th quarter of 2015, the shocks increased above zero in October and December 2015.

Figure 3:1 BWR Monetary shock series from Jan. 2014 to Dec. 2020



Appendix Figures C.1– C.5 shows the changes in renewable energy capacity each month. The states that experience a change in renewable energy capacity are denoted RC=1 and are summed together for that month, while states with no change are denoted RC=0 and added together. The states with RC=1 for a given month are the blue stacked areas in the plots, while those with RC=0 are the notated orange stacked areas. The plots show the distribution of responses of renewable energy capacity to various exogenous factors.

Appendix Figures C.1 shows the plot for total renewable energy. August 2014 and 2015, April 2016, February 2017 and 2018, and March 2019 marked the months where many states experienced changes in renewable energy capacity, while June 2014, November 2015 and 2016, January 2017, December 2018, September 2019, and June 2020 marked the months with fewer states experience changes in capacity. It is reasonable to assert that the changes in renewable energy capacity are random and are devoid of seasonal weather patterns but rather due to exogenous factors such as changes in costs (e.g., direct cost, servicing and maintenance cost, interest rates, investment cost, etc.), energy price shocks, and overall economic shocks. Furthermore, from all the renewable energy sources, more states experienced changes in solar energy capacity, and the plot is as dense as the total capacity (Appendix Figures C.2– C.5).

3.4.1 Probit Estimation

The Probit regression results[33] demonstrate the relationship between monetary shocks and renewable energy. The results are presented in Tables 3:1 – 3:3. The robustness of the results is checked by IV Probit (Appendices C.3– C.7)

Table 3:1 shows the impact of monetary policy on total renewable energy capacity. Across all specifications, the marginal effects range between -1.01% to -0.87% and are statistically significant. The results reveal a high likelihood that monetary policy shock will lead to total renewable energy capacity changes. In model 1, an unanticipated 10 basis point fall in interest rates causes a 0.095% increase in the probability of a state changing its renewable energy capacity.

[33] Columns 1 – 8 represent different model specifications. Column 1 displays the results of a regression specification using only monetary policy shocks as predictors. Columns 2 – 3 include renewable energy consumption and its interaction with Cooling Day, respectively. Column 4 includes all predictors. Column 5 omits energy consumption from the specification Column 4. Columns 6 – 8 represent results for the specification using each energy price.

Table 3:1 Total Renewable Energy Capacity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rate_shock	-0.95***	-1.00***	-1.01***	-1.00**	-0.87***	-0.92***	-0.87***	-0.94***
	(0.23)	(0.24)	(0.25)	(0.26)	(0.24)	(0.23)	(0.23)	(0.23)
Tot_RewCons	-	0.33***	0.33***	0.35***	-	-	-	-
		(0.11)	(0.11)	(0.12)				
Tot_RewCons_Cool	-		0.00	-0.00		-	-	-
			(0.00)	(0.00)				
NatGas_Price	-	-	-	0.04	-0.001	-0.02	-	-
				(0.03)	(0.03)	(0.03)		
Crude_Price	-	-	-	-0.02	-0.03	-	-0.03	-
				(0.02)	(0.02)		(0.03)	
Electric_Price	-	-	-	0.01	-0.02	-		-0.05
				(0.12)	(0.11)			(0.10)
Number of obs.	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100

Notes: Parameters are the estimated marginal effect from the Probit model. ***, ** and * indicate significance at the 1%, 5% and 10% levels.

This outcome aligns with the conventional understanding that higher interest rates suppress investment in capital-intensive sectors. When the cost of financing renewable energy projects increases, then investment in renewable energy is discouraged. Existing studies, such as Bernanke and Gertler (2012), have shown that restrictive monetary policies can reduce aggregate energy demand and, by implication, stifle capacity expansion of renewable energy infrastructures. Indeed, tight monetary conditions may undermine strong policy support geared towards renewable expansion. Similarly, the study of Detemple, Kitapbayev & Reppen (2024) underscored that a higher interest rate usually increases the value of an energy power project but can have mixed effects if there are significant subsidies. The authors alluded that, under a fixed-price contract, the value of a power installation project falls, and it becomes better to postpone investments when interest rates go up. The author's findings are consistent with the results in this analysis, suggesting that renewable energy, like other tangible assets, is sensitive to monetary policy shifts.

This finding in this study also corroborates the VAR results of Chen & Lin (2024), which examined the relationship between monetary policy and renewable energy production based on the U.S. quarterly data from 1900 to 2002. The authors proved that contractionary monetary policy causes renewable energy production to fall.

Changes in asset prices can be a mechanism through which monetary policy affects renewable energy. Indeed, the size of the shock transmitted from the Fed's monetary actions depends on how the renewable energy market is exposed to financial market conditions. Monetary announcements that signal volatility in market prices would change the risk and return sentiments of forward-looking investors in renewable energy. An expansionary policy can lead to increased asset prices, increased incentives for funding renewable energy projects and higher returns on renewable projects.

The impact of renewable energy consumption on renewable energy capacity is positive. The results in models 3 and 5 in Table 3:1 show that a 1% increase in total renewable energy consumption will result in a 0.33% and 0.35% increase in the probability of the state changing renewable energy capacity, which is statistically significant. The result is consistent with the findings that increasing demand for green energy plays a crucial role in the continuous development of renewable energy. These outcomes support the theory of increasing returns, where higher consumption reinforces the growth cycle and improvement in renewable energy capacity. As consumption increases, the rise in market confidence and demand stability makes investments more attractive.

Recently, many industries have prioritized efficiency in the use of energy to reduce energy costs and minimize their environmental footprints, goals that can quickly be realized through an increase in renewable energy in their energy mix. These outcomes can be achieved through PPA contracts that offer zero-interest financing to developers, all of which contribute to an increase in renewable energy development.

The effects of energy prices on the total capacity of renewable energy are not statistically significant.

This study investigates the impacts of monetary shocks on the installed capacity of different renewable energy sources, such as hydroelectric, biomass, solar, and wind.

The results in Table 3:2 show the analyses of the probability of changes in traditional hydroelectric energy capacity due to monetary shock, hydro-renewable energy consumption and prices. The marginal effects show that an unanticipated decrease in interest rate by 10 basis points increases the probability of hydroelectric capacity to change by approximately 0.049%, 0.031% and 0.03% in models 1, 2 and 3, respectively.

Table 3:2 Hydroelectric Energy Capacity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rate_shock	-0.49***	-0.31***	-0.30***	-0.30**	-0.55***	-0.52***	-0.56***	-0.48***
	(0.11)	(0.10)	(0.10)	(0.10)	(0.12)	(0.12)	(0.12)	(0.11)
Hy_RewCons	-	0.19***	0.18***	0.18***	-	-	-	-
		(0.04)	(0.04)	(0.04)				
Hy_RewCons_Cool	-	-	0.00 (0.00)	0.00 (0.00)	-	-	-	-
NatGas_Price	-	-	-	-0.02	0.01	0.04***	-	-
				(0.02)	(0.02)	(0.01)		
Crude_Price	-	-	-	0.01	0.03*	-	0.04***	-
				(0.02)	(0.02)		(0.01)	
Electric_Price	-	-	-	0.05	0.08	-		0.11*
				(0.05)	(0.06)			(0.06)
Number of obs.	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100

Notes: Parameters are the estimated marginal effect from the Probit model. ***, ** and * indicate significance at the 1%, 5% and 10% levels.

This inverse relationship suggests that the probability of expanding hydroelectric capacity diminishes as monetary shocks increase (e.g., through higher interest rates or immense financial volatility). This result aligns with the concept that increased monetary shocks increase the cost of capital or introduce financial constraints, particularly impacting capital-intensive projects like hydroelectric infrastructure (Olujobi et al., 2023). As the size of monetary shocks rises, it deters investment in hydroelectric projects by making financing more costly or shifting investor preferences away from long-term infrastructure investments that require substantial upfront capital (IEA, 2024).

Using the state of California, for example, which is known for its ambitious clean energy policies and goals, large infrastructure projects like hydroelectric installations require substantial investment and stable financing conditions (Newsom, 2023). When monetary shocks increase—whether through rising interest rates or heightened financial market volatility — the associated increase in borrowing costs can make securing affordable financing for capital-intensive projects challenging. Given California's high cost of living and strict environmental regulations, increased interest rates or financial uncertainty may deter private and public entities from pursuing new hydroelectric investments, even when these align with the state's clean energy targets (Baker et al., 2020). The higher the interest rate level, the longer the payback periods for capital-intensive projects and the greater the sensitivity to financing costs (Barbose et al., 2019).

In Washington, a state that relies heavily on hydroelectric power—accounting for nearly two-thirds of its total electricity generation—the impact of monetary shocks can similarly dissuade investment in hydroelectric expansion (U.S. EIA, 2023).

The outcomes of the results of these models corroborate the study of Akan (2024), which earlier examined the indirect effects of monetary policy on climate change and how it influences financial asset prices, sectoral output, and renewable energy use. The study uses structural equation modelling to evaluate proxies like stock prices, bank credits, industrial production, transportation, residential consumption, and various renewable sources. The author's key findings reveal that monetary policy's impact on climate change varies by sector and energy type. The study concludes by emphasizing tailored strategies and renewable energy reforms to expedite climate goals.

Other covariates, such as electricity, natural gas, and crude oil prices, significantly affect the probability of increasing renewable energy installation. Since oil is rarely used for electricity, crude oil prices would not directly impact renewable energy capacity. The results support the hypothesis that energy prices enhance the expansion of renewable hydroelectric capacity. The significance of the energy price parallels the price substitution effect theory on household spending, where the higher price of substitute fossil energy increases the consumption of cheaper alternatives.

Table 3:3 displays the Probit regressions for bioenergy capacity. The results indicate that bioenergy consumption, electricity prices, and natural gas prices have no significant impact on installed capacity. However, monetary policy shocks and crude oil prices contribute to the variations in bioenergy capacity.

Table 3:3 Bio Energy Capacity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rate_shock	-0.37***	-0.17	-0.17	-0.36**	-0.44***	-0.37***	-0.45***	-0.36***
	(0.13)	(0.14)	(0.14)	(0.15)	(0.14)	(0.14)	(0.14)	(0.14)
Bio_RewCons	-	-0.00	-0.00	-0.10	-	-	-	-
		(0.08)	(0.08)	(0.07)				
Bio_RewCons_Cool	-	-	0.00	-0.00	-	-	-	-
			(0.00)	(0.00)				
NatGas_Price	-	-	-	-0.04*	-0.04	0.00	-	-
				(0.02)	(0.02)	(0.01)		
Crude_Price	-	-	-	0.06***	0.06***	-	0.04	-
				(0.02)	(0.02)		(0.14)	
Electric_Price	-	-	-	0.07	0.07	-		0.07
				(0.05)	(0.05)			(0.05)
Number of obs.	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100

Notes: Parameters are the estimated marginal effect from the Probit model. ***, ** and * indicate significance at the 1%, 5% and 10% levels.

Across the specifications in models 1, 4 – 8, an unanticipated decrease in interest rate by 10 basis points led to an approximate increase in bioenergy between 0.036% and 0.045%, respectively. These results support the intuition that financial tightening reduces investment in renewable energy sectors, including bioenergy. The significant and negative relationship between monetary shocks and bioenergy capacity aligns with the economic investment theory (Dixit & Pindyck, 1994). Higher interest rates or financial instability can increase the cost of capital and make long-term investments in bioenergy less attractive. This result is also consistent with empirical findings by Aklin and Urpelainen (2018), which underscored that renewable energy investment tends to slow down during periods of monetary tightening due to higher financing costs and increased uncertainty.

The result revealed that electricity and natural gas prices barely affect bioenergy. However, a strong relationship exists between crude oil price (Crude_Price) and bioenergy capacity. In models 4 and 5, a one-unit increase in the crude oil price causes bioenergy capacity to change by 0.06%. Higher electricity prices may incentivize investment in bioenergy and, therefore, serve as a competitive source of energy generation.

Appendices C.1 – C.2 presents the Probit regression results for solar and wind installed capacity. The results are not statistically significant across all model specifications. The factors affecting wind and solar energy are many and complex (Rule, 2014). Technological advancements have significantly reduced solar and wind energy installation costs in recent years. The government's support through policy tools, such as subsidies, tax incentives, and renewable energy mandates, has minimized the risk associated with the investment and increased the production of wind and solar energy. Although monetary tools, such as low interest rates, play a crucial role in determining the dynamics of some of the highlighted factors, the result shows that monetary policy has a limited role in wind energy development. Wind and solar energy projects, characterized by long payback periods, still rely more on targeted financial mechanisms and multi-technology configurations of solar and wind projects (Miller et al.,2017; Derré, 2024). Consequently, the results from this study show that while monetary policy can create favorable conditions for overall renewable energy development, the significant causes of growth in wind and solar energy primarily lie in targeted interventions and the cost of the technologies.

3.4.2 IV Probit Estimation

This subsection provides outcomes based on the IV Probit model to verify the validity, reliability, and stability of the Probit model. The p-values for the Wald test show no substantial evidence that the IV model suffers from gross endogeneity.

Columns 1 – 4 in Appendices C.3 – C.7 represent the IV specifications of columns 2, 6, 7, and 8 in Table 3:1 – 3:3 and Appendix C.1 – C.2. In many instances, the outcomes of the IV Probit in Appendix C3 are consistent with the result of the Probit estimation as initially obtained. The coefficient of monetary policy is statistically significant across all model specifications.

The obtained inverse relationship indicates that monetary tightening through an increase in interest rates considerably decreases the tendency to change total renewable energy capacity after controlling for endogeneity. For instance, in column 1 of Appendix C.3, an unanticipated 10-basis point increase in interest rate results in a 0.26% decrease in the probability of a state-changing total renewable energy installed capacity. A very similar effect is found in columns 2 to 4. This outcome is identical and improves on the coefficient of the Probit model in column 2 of Table 3:1. This finding aligns with the conventional understanding that higher interest rates can suppress investment in capital-intensive sectors such as renewable energy.

The significant positive effect of renewable energy consumption on renewable energy capacity is reinforced in the IV Probit model. The estimate revealed that a 1% increase in total renewable energy consumption leads to a 0.91% increase in the probability of state-changing renewable energy capacity. The magnitude of the coefficient with IV is greater than the outcomes obtained in the Probit model. The finding parallels the results reported in the Marques and Fuinhas (2011) study, demonstrating a positive relationship between renewable energy consumption and growth, especially in developed economies.

Contrary to the results obtained in Table 3:1, the results reveal a significant inverse relationship between natural gas prices and the probability of changing renewable energy capacity, with a coefficient of -0.36, indicating that as in natural gas price increases by one unit, the likelihood for changing renewable energy installation declines by 0.36%. Comparing this outcome with the insignificant result in the Probit model in Table 3:1 confirms that, on the aggregate level, natural gas and renewable energy are best served as complementary energy sources. This outcome is statistically significant; however, it is counterintuitive. Higher natural gas prices typically raise production costs for industries that rely heavily on this energy source, reducing the aggregate demand for renewable energy. As natural gas prices rise, the substitution effect between natural gas and renewable energy is expected to make renewables more attractive, increasing the likelihood of renewable energy development. Nonetheless, on an aggregate level, renewable and traditional energy sources appear complementary rather than substitutes.

In some regions, such as the northwestern U.S., natural gas is a transitional bridge between coal and renewables. When natural gas prices are low, it becomes an attractive alternative to coal, which can result in reduced reliance on coal and a more immediate economic incentive to invest in renewable energy. However, as natural gas prices increase, states may not be as inclined to switch directly from coal to renewables because the higher cost of natural gas makes it less economically appealing to phase out coal. According to Jenkins & Thernstrom (2017), there could be a scenario where natural gas and renewables are being used complementary (e.g., natural gas plants supporting renewable energy during periods of low generation, such as at night or during low wind periods). Due to the intermittent operation of renewable machines, increased natural gas prices might also lead to increased investment in renewable technology since gas-fired plants remain essential for balancing intermittent renewables (Bushnell & Novan, 2018). Solar and wind replace coal but challenge grid reliability due to their variability. With limited storage options and insufficient nuclear power, only natural gas can ensure stability during the transition (Gaster, 2024). Gas energy plays a flexible backup role for renewable energy, and higher natural gas prices can potentially increase renewable investment competition.

In comparison with extant studies such as that of Sarmiento et al. (2021), which explore the impact of natural gas prices on the power systems of Mexico and the U.S., they found that high natural gas prices boost short-term carbon-intensive technologies and increase renewable investments in the long-term.

Furthermore, electricity prices have a negative and significant effect on determining the probability of renewable energy change. The IV result is statistically significant compared with the result in Table 3:1. One unit increase in electricity prices brings about a 2.75% decline in total renewable energy change probability. Higher electricity prices can indicate high energy costs, which impact the consumption behavior of household and business sectors. Typically, when electricity prices rise, consumers face higher utility bills, and producers may see increased production costs. This situation can lead to economic cost-push inflationary effects, reducing overall demand and investment capacity, including renewable energy projects. With lower demand, utilities may reduce the planned renewable energy project due to weaker demand projections. Helm (2017) averred that integrating renewable energy can come with substantial costs, which may be unattractive if electricity prices are already elevated. The crude oil prices do not affect the total renewable energy change probability.

Appendix C.4 presents the results of an IV estimation model analyzing the probability of changes in hydroelectric energy capacity with respect to monetary shock, hydro-renewable energy consumption, natural price, crude price, and electricity price. The results indicate significant adverse effects of monetary shock on the hydroelectric energy capacity change. A 10-basis point increase in interest rate leads to a decrease of approximately 0.31%, 0.33% and 0.35% in the probability of hydroelectric capacity change in models 1, 2 and 3, respectively. The exogeneity of the estimation in the three models cannot be rejected based on the Wald test p-values.

Other covariates, such as electricity prices and crude oil prices, have significant positive effects on renewable energy installation, as shown in Model 8 of Table 3:2. However, the IV estimate produced more significant electricity and crude oil price coefficients than the Probit model. The positive outcomes of crude price in both the Probit and IV Probit models confirm that higher energy prices enhance the attractiveness of expanding cheaper, clean and low-carbon hydroelectric capacity. This finding suggests that energy prices provide the incentive to shift investment from traditional energy sources to alternative renewables

Appendix C.5 presents the outcome of estimating the monetary shock on the probability of bioenergy capacity change using the IV approach to account for potential endogeneity to the result obtained in Table 3:3. Across the specifications in columns 1 to 3, the monetary policy shock has a negative coefficient and is statistically significant. A 10-basis point decrease in interest rate leads to an increase of approximately 0.24%, 0.20% and 0.22% in the probability of bioenergy capacity change in models 1, 2 and 3, respectively, which are representative of the specification in columns 2, 6 and 7 of Table 3:3. This result further supports the intuition that economic uncertainty or financial tightening reduces investment in renewable energy sectors and makes long-term investments in bioenergy less attractive.

The result revealed that electricity prices are positive and significant in impacting the probability of bioenergy capacity change. A unit increase in the price of electricity results in a 3.50% increase in the likelihood of Bioenergy capacity change. Higher electricity prices may incentivize investment in bioenergy, which can serve as a competitive source of energy generation. Crude Oil Price in column 3 has a positive and significant effect. That is, the probability of changes in bioenergy capacity increases by 0.17% as the price of crude oil increases by one unit. The test for homogeneity is rejected in models 1 and 2, which implies weak instruments.

In Appendices C.6 – C.7, the impact of the monetary policy shock on solar and wind capacity cannot be ascertained in the IV Probit model, as in the Probit Model. As earlier suggested, the lack of significance could be attributable to several factors that insulate solar investments from short-term monetary fluctuations, reducing the immediate impact of monetary shocks on capacity expansion. Some of these factors revolve around the stability of financing for solar and wind energy capacity from financial institutions. Often, renewable energy developers turn to companies to secure funds through Power Purchase Agreements (PPAs). Direct PPAs, which involve a fixed contract between an energy provider and a buyer, typically lock in prices and terms for long years, insulating projects from the impact of short-term monetary policy changes, such as interest rate fluctuations. Since wind and solar energy are the predominant sources in PPAs due to their cost of technology, their development may be largely unaffected by short-term monetary policy. As a result, while monetary policy influences another form of renewable energy, its effects on solar and wind projects under long-term PPAs are minimal.

Additionally, there are many renewable energy regulations and support programs that determine the energy mix of the states, with an emphasis on wind and solar energy. Examples are New York’s Reforming the Energy Vision (REV), Massachusetts’ SMART (Solar Massachusetts

Renewable Target) program, New Jersey's Clean Energy Program and the Solar Renewable Energy Certificate (SREC). These factors tend to have a more significant long-term effect on solar and wind energy investment than the short-term fluctuation in the interest rate.

3.5. Conclusion

The growing regulations to reach decarbonization goals have created a desire for more investment in renewable energy in the United States, leading the industry to respond to shocks in the monetary policy of the Federal Reserve of the U.S. The periodic FOMC announcements on interest rates and economic projections —like other tangible assets — have shocked renewable energy investment in recent years. Therefore, this study seeks insight into the changes in renewable energy capacities from unanticipated monetary shocks between 2014 and 2020.

The renewable energy capacity of different sources is transformed into a binary variable to isolate the noise that affects renewable energy utilization. The analysis uses the monthly BRW shock series (2014–2020) to capture the unanticipated monetary shocks, distinguishing the shocks from traditional, often anticipated, monetary policy shocks. The relative costs of alternative energy sources and energy prices can significantly affect renewable energy utilization. Therefore, the analysis also includes energy prices (crude oil, natural gas, and electricity prices) to determine the complementarity and substitutability relationship between renewable and traditional energy sources. This study employs the Probit and IV Probit models for potential feedback causality between renewable energy investment and energy prices.

The findings suggest that monetary shocks influence the utilization of renewable energy capacities. However, no statistically significant relationship was found between monetary shocks and specific renewable sources, such as wind and solar energy. Within the scope of this study, the results show evidence of complementarity between aggregate renewable energy and traditional energy sources. Furthermore, when renewable energy is disaggregated to different sources, bioenergy and hydroelectric energy emerge as substitutes for conventional energy sources.

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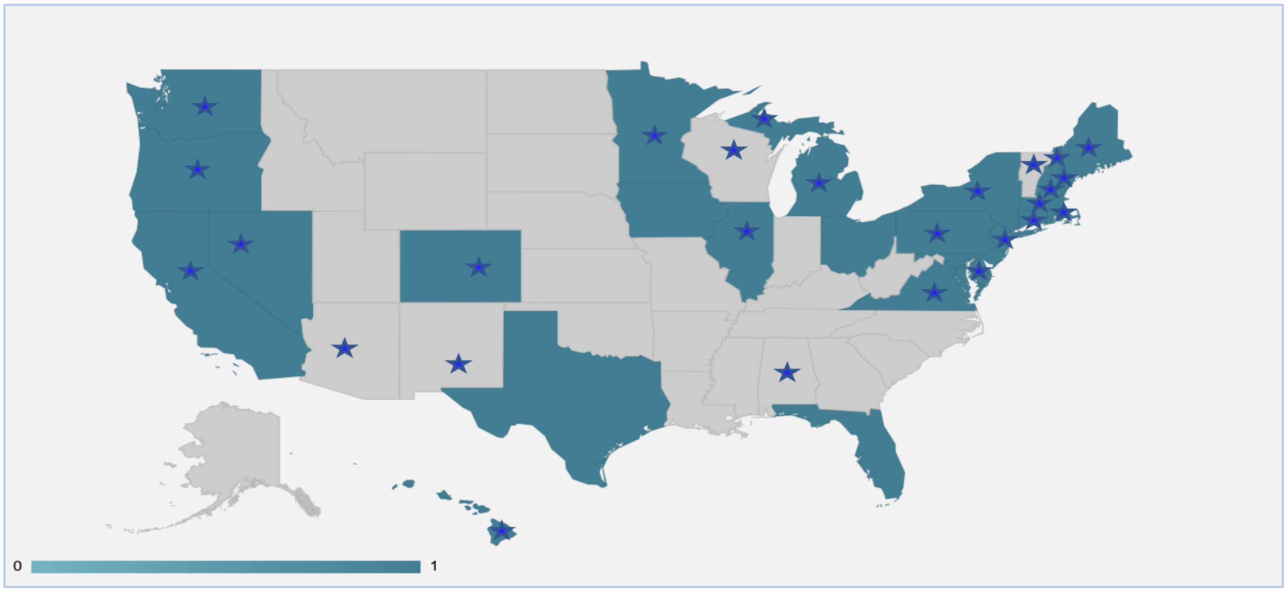
Appendix Figures B: Chapter 2

Appendix Figure B: Disclosure Policy

Appendix Figure B.1: Summary Maps of Geographical Overview of States that Promote Disclosure Policy



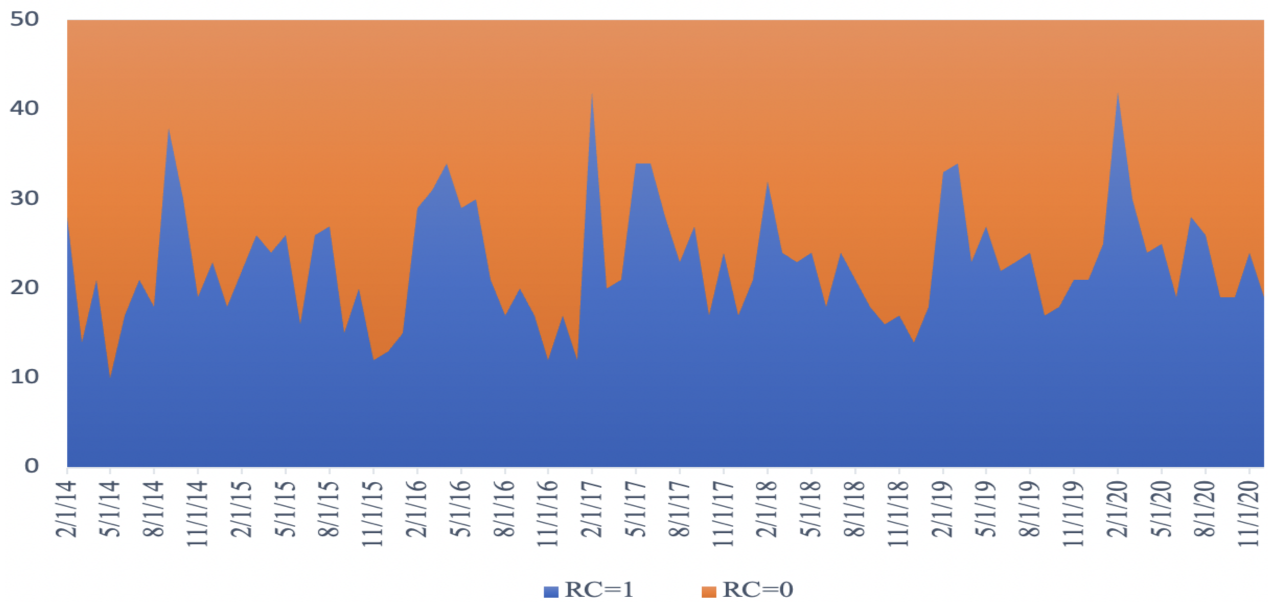
Source: Database of States Incentives for Renewable Energy (DSIRE). https://programs.dsireusa.org/system/program

Note: The starred states are the democrat states based on the summary of statewide results of the 2008, 2012, 2016,

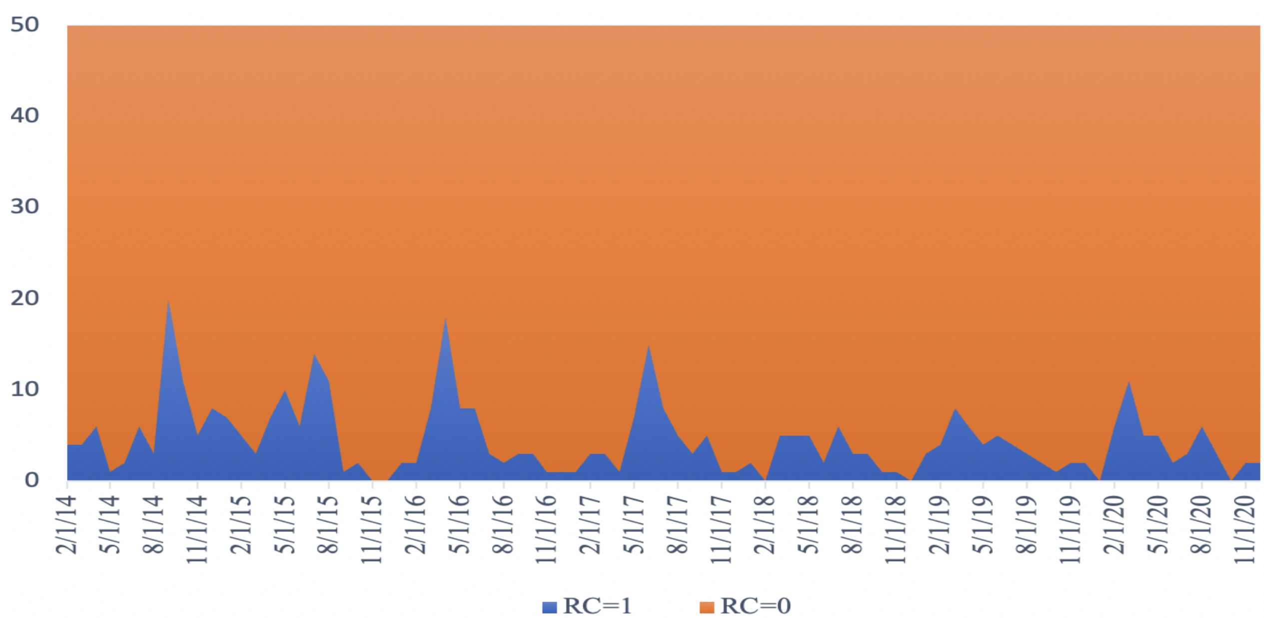
Appendix Figures C: Chapter 3

Appendix Figure C: Descriptive Statistics of Renewable Energy Sources

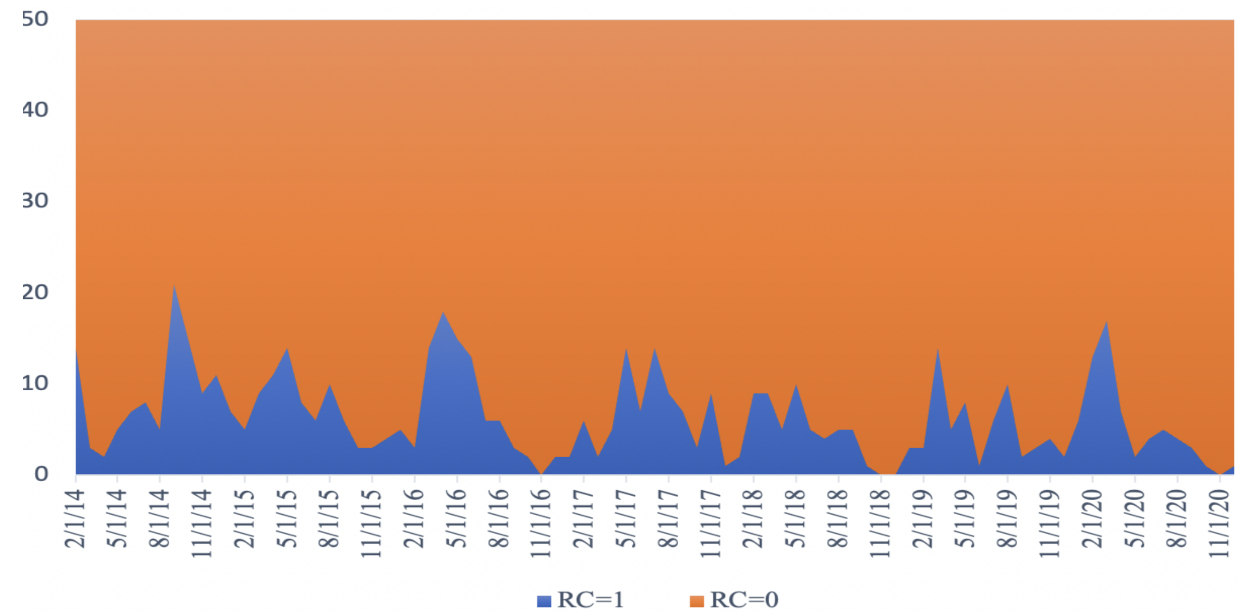
Appendix Figure C.1: Count of States Experiencing Changes in Total Renewable Installed Capacity in a Month



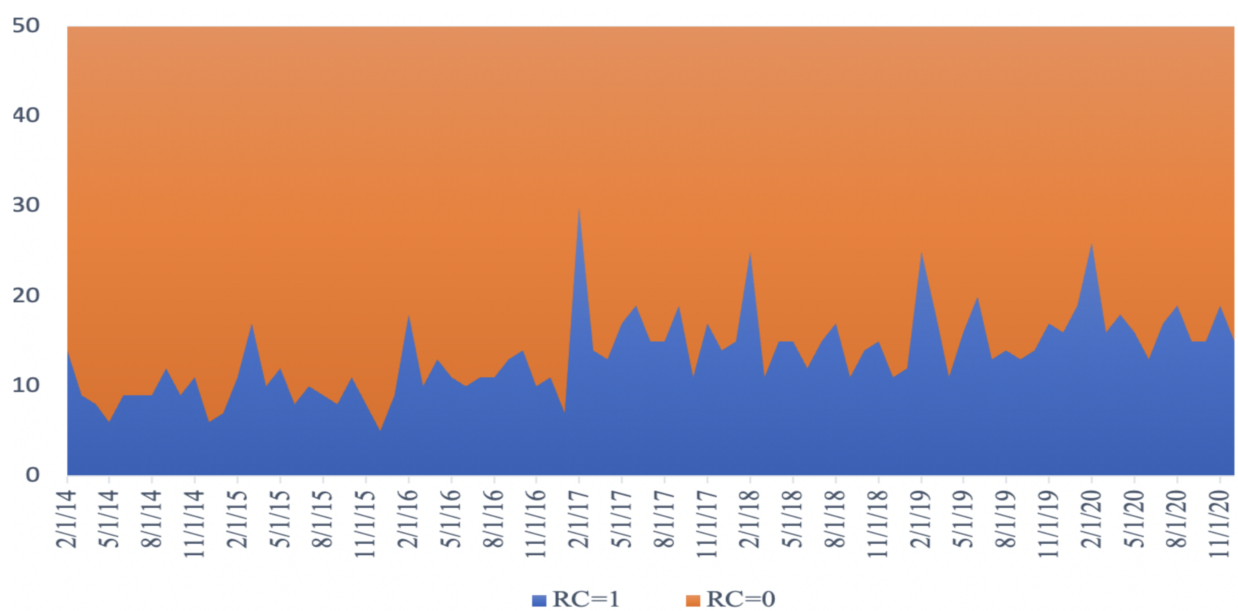
Appendix Figure C.2: Count of States Experiencing Changes in Hydroelectric Energy Installed Capacity in a Month



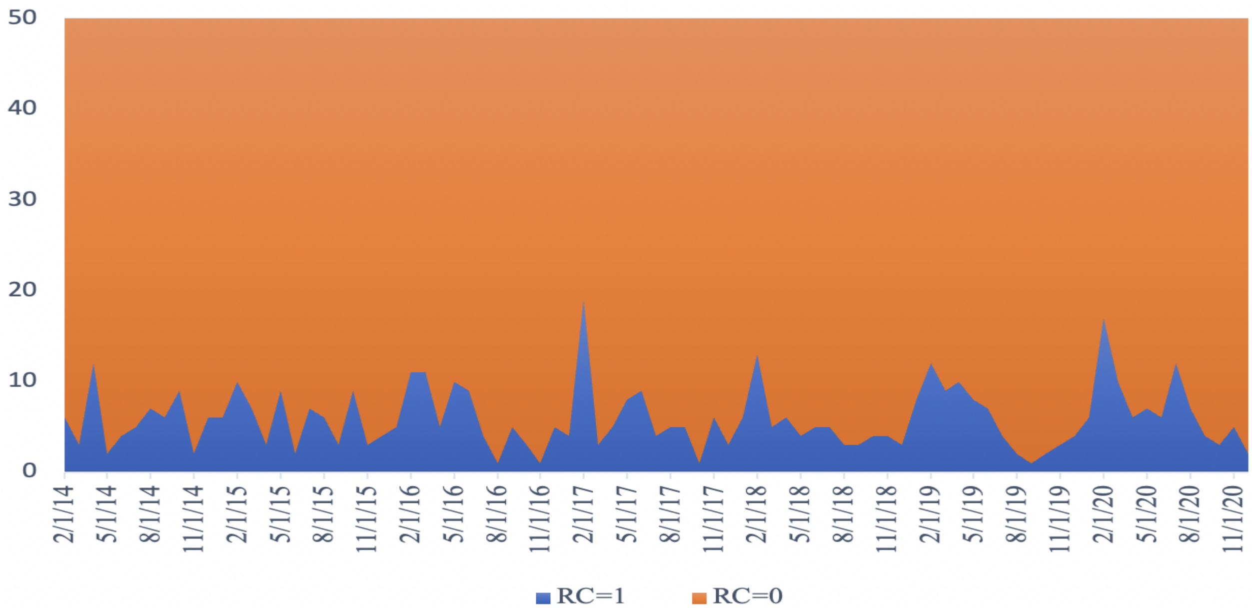
Appendix Figure C.3: Count of States Experiencing Changes in Bioenergy Installed Capacity in a Month



Appendix Figure C.4: Count of States Experiencing Changes in Solar Energy Installed Capacity in a Month



Appendix Figure C.5: Count of States Experiencing Changes in Wind Energy Installed Capacity in a Month



50
40
30
20
10
0
2/1/14
5/1/14
8/1/14
11/1/14
2/1/15
5/1/15
8/1/15
11/1/15
2/1/16
5/1/16
8/1/16
11/1/16
2/1/17
5/1/17
8/1/17
11/1/17
2/1/18
5/1/18
8/1/18
11/1/18
2/1/19
5/1/19
8/1/19
11/1/19
2/1/20
5/1/20
8/1/20
11/1/20
RC=1
RC=0

Appendix A: Chapter 1

Appendix A Cumulative Responses of Electricity Prices and Economic Activities to Renewable for 2010 break date

Appendix B.1 24-Month Cumulative Electricity Price Response to Renewable Shocks based on ACEE Classification

Shock%	Ranks 1-10	Ranks 11-20	Ranks 21-30	Ranks 31-40	Ranks 41-50
1	-0.111	-0.524	-0.003	0.075	-0.001
5	-0.612	-2.702	-0.052	0.278	-0.001
10	-1.234	-5.357	-0.114	0.533	0.001

* States ranked based on their energy efficiency performance from ACEEE's indices.

Appendix A.2 24-Month Cumulative Economic Activity Response to Renewable Shocks based on ACEEE

Shock%	Ranks 1-10	Ranks 11-20	Ranks 21-30	Ranks 31-40	Ranks 41-50
1	0.172	0.176	0.159	0.140	0.156
5	0.177	0.189	0.160	0.140	0.156
10	0.184	0.211	0.162	0.140	0.156

*States ranked based on their energy efficiency performance from ACEEE's indices

Appendix B: Chapter 2

Appendix B Data Source and Description

Appendix B.1 Data

Name	Description	Source
GreenHouse Gas (GHG) Emission	Carbon dioxide (CO2), Sulfur-dioxides (SO2), and Nitrogen-oxides (NOx) from electricity power industry measured in thousand metric tons	Energy Information Administration (EIA), Environmental Data.
Share of Democrat (Dem_ratio)	The ratio of total to democrat representatives in each state	Library of Congress https://www.congress.gov
Disclosure Policy (I)	Disclosure program based on year implemented	Database of States Incentives for Renewable Energy (DSIRE)

Energy Efficiency	Multi-sectoral energy efficiency scores of states in the U.S. computed by the American Council for an Energy-Efficient Economy (ACEEE)	https://programs.dsireusa.org/system/program https://www.aceee.org/

Appendix C: Chapter 3

Appendix C Solar, Wind and IV Results

Appendix C.1 Solar Energy Capacity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rate_shock	-0.26	-0.20	-0.21	-0.14	-0.12	-0.21	-0.11	-0.26
	(0.20)	(0.21)	(0.21)	(0.22)	(0.21)	(0.21)	(0.21)	(0.20)
Solar_RewCons	-	0.04	0.05*	0.08**	-	-	-	-
		(0.02)	(0.03)	(0.03)				
Solar_RewCons_Cool	-	-	-0.00	-0.00	-	-	-	-
			(0.00)	(0.00)				
NatGas_Price	-	-	-	0.02	-0.02	-0.06*	-	-
				(0.03)	(0.03)	(0.03)		
Crude_Price	-	-	-	-0.03	0.06***	-	-0.07***	-
				(0.02)	(0.02)		(0.02)	
Electric_Price	-	-	-	-0.02	0.06	-	-	-0.14
				(0.10)	(0.12)			(0.11)
Number of obs.	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100

Notes: Parameters are the estimated marginal effect from the Probit model. ***, ** and * indicate significance at the 1%, 5% and 10% levels.

Appendix C.2 Wind Energy Capacity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rate_shock	-0.14	-0.16	-0.18	-0.18	-0.12	-0.11	-0.09	-0.15
	(0.17)	(0.17)	(0.17)	(0.19)	(0.18)	(0.17)	(0.18)	(0.18)
Wind_RewCons	-	0.04	0.02	0.02	-	-	-	-
		(0.03)	(0.03)	(0.02)				

Wind_RewCons_Cool	-	-	-0.00 (0.00)	-0.00 (0.00)	-	-	-	-
NatGas_Price	-	-	-	0.00 (0.03)	-0.01 (0.02)	-0.03 (0.01)	-	-
Crude_Price	-	-	-	-0.01 (0.02)	-0.01 (0.02)	-	-0.02 (0.02)	-
Electric_Price	-	-	-	-0.11 (0.07)	-0.13* (0.08)	-		-0.15* (0.08)
Number of obs.	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100

Notes: Parameters are the estimated marginal effect from the Probit model. ***, ** and * indicate significance at the 1%, 5% and 10% levels.

Appendix C.3 IV Estimation: Total Renewable Energy]

(Columns 2, 6,7 & 8 of Table 3:1)

	(1)	(2)	(3)	(4)
Rate_shock	-2.61*** (0.68)	-2.15*** (0.69)	-2.22*** (0.69)	-2.16** (0.85)
Tot_RewCons	0.91** (0.36)	-	-	-
NatGas_Price	-	-0.36*** (0.14)	-	-
Crude_Price	-	-	-0.11 (0.07)	-
Electric_Price	-	-	-	-2.75*** (0.99)
First stage: Hasen J test (p-value) Exogeneity	0.89	0.08	0.31	0.12
Number of obs.	4,100	4,100	4,100	4,100

Notes: Parameters are the estimated marginal effect from the IV Probit model. ***, ** and * indicate significance at the 1%, 5% and 10% levels.

Appendix C.4 IV Estimation: Hydroelectric Energy Capacity

(Columns 2, 6,7 & 8 of Table 3:2)

	(1)	(2)	(3)	(4)
Rate_shock	-3.10*** (1.05)	-3.29*** (1.05)	-3.46** (1.06)	-0.36 (0.89)
Hy_RewCons	0.78 (0.72)	-	-	-
NatGas_Price	-	0.26 (0.20)	-	-
Crude_Price	-	-	0.17* (0.09)	-
Electric_Price	-	-	-	3.31***

				(0.57)
Wald test (p-value) Exogeneity	0.78	0.10	0.15	0.002
Number of obs.	4,100	4,100	4,100	4,100

Notes: Parameters are the estimated marginal effect from the IV Probit model. ***, ** and * indicate significance at the 1%, 5% and 10% levels.

Appendix C.5 IV Estimation: Bio Energy Capacity

(Columns 2, 6,7 & 8 of Table 3:3)

	(1)	(2)	(3)	(4)
Rate_shock	-2.35***	-2.03***	-2.24**	-0.43
	(0.89)	(0.88)	(0.89)	(0.60)
Bio_RewCons	1.38***	-	-	-
	(0.48)			
NatGas_Price	-	0.16	-	-
		(0.19)		
Crude_Price	-	-	0.17**	-
			(0.08)	
Electric_Price	-	-	-	3.50***
				(0.10)
Wald test (p-value) Exogeneity	0.002	0.19	0.06	0.00
Number of obs.	4,100	4,100	4,100	4,100

Notes: Parameters are the estimated marginal effect from the IV Probit model. ***, ** and * indicate significance at the 1%, 5% and 10% levels.

Appendix C.6 IV Estimation: Solar Energy Capacity

(Columns 2, 6,7 & 8 of Appendix C.1)

	(1)	(2)	(3)	(4)
Rate_shock	-0.52	-0.44	-0.51	-1.17**
	(0.73)	(0.72)	(0.73)	(0.58)
Solar_RewCons	0.28***	-	-	-
	(0.05)			
NatGas_Price	-	-0.63***	-	-
		(0.14)		
Crude_Price	-	-	-0.19***	-
			(0.07)	
Electric_Price	-	-	-	-2.90***
				(0.10)
Wald test (p-value) Exogeneity	0.23	0.00	0.06	0.00
Number of obs.	4,100	4,100	4,100	4,100

Notes: Parameters are the estimated marginal effect from the IV Probit model. ***, ** and * indicate significance at the 1%, 5% and 10% levels.

Appendix C.7 ` IV Estimation: Wind Energy Capacity

(Columns 2, 6,7 & 8 of Appendix C.2))

	(1)	(2)	(3)	(4)
Rate_shock	-0.73	-0.67	-0.54	-0.65
	(0.92)	(0.93)	(0.92)	(1.14)
Wind_RewCons	-0.00	-	-	-
	(0.18)			
NatGas_Price	-	0.07	-	-
		(0.18)		
Crude_Price	-	-	0.09	-s
			(0.08)	
Electric_Price	-	-	-	0.30
				(2.27)
Wald test (p-value) Exogeneity	0.14	0.01	0.87	0.79
Number of obs.	4,100	4,100	4,100	4,100

Notes: Parameters are the estimated marginal effect from the IV Probit model. ***, ** and * indicate significance at the 1%, 5% and 10% levels.