Renewable Energy and Infrastructure Investment: The Effectiveness of a Tax Incentive on Growth

Project Leader: Jin Sung (Alex) Yoon[1*]
Researchers: Renato de Angelis, Davis Turner, Phil Horrigan, Daniel Werner,
Andrew Moukabary, Joachim Laurent, Vichar Lochan,
Grace Hu, June Lu, Marcus Amine, Drew Mukherjee

[1]The Paul Douglas Institute, The University of Chicago

Abstract

Renewable energy (RE) investment is a necessary step towards reducing carbon emissions worldwide while meeting growing energy demand. There are many policies that seek to support a growth in RE capacity, with varying degrees of both political and economic success. Given the complex nature of energy markets and transmission, any concentrated effort of both public and private entities to make the green transition will result in inevitable trade-offs. Thus, in this paper, we first qualitatively analyze the political realities of RE investment and policy status in the United States, subsequently proposing an econometric analysis of the effectiveness of a specific support policy—tax incentives—in the United States using panel data and a time-series regression framework. The results—which we stress should be considered a preliminary analysis that seeks to raise further research topics—show that there are significant relationships between RE investment growth and the implementation of tax incentives. Such results suggest that, with support policies, the United States may be able to reach a double objective: increasing energy capacity and investment while also reducing carbon emissions and reaching a greener future. Our research also highlights potential future research areas and statistical analyses that may provide deeper and greater insight into the effectiveness of tax incentives on RE investment growth.

1. Introduction

To meet the emission standards as outlined by the Paris Climate Agreement, the United States must play an international role keeping warming below the 1.5 degree Celsius threshold by 2030 [1]. Accordingly, it is impossible for the United States to ensure such a threshold is reached unless greenhouse emissions drop by at least 43% by 2030. The status quo suggests that the United States is making poor strides at achieving such a goal, even with the historic investment in fighting climate change from the most recent infrastructure bill signed by President Biden in 2022.

The State of Illinois has set ambitious emission standards in the coming years in an effort to become a national leader in green energy and to help the United States hit national climate agreements [2]. However, the state's existing challenging energy landscape makes it difficult to foresee this future of renewable energy growth per capita nationwide without the addition of a support policy alongside existing energy investment in the state. Come 2025, just two years from now, Illinois has a legislative mandate to source 25 percent of the state's energy from renewable resources by 2025, placed on all utilities and alternative energy suppliers [3]. Further, the Climate and Equity Jobs act, passed in 2021, commits the state to an ambitious 40% renewable energy target by 2030 and 50% renewable energy by 2040 [4].

Illinois faces pressing electricity challenges as it relates to their long-term diversification of electricity production and ability to feasibly adopt renewable energy into their portfolio. Illinois is a key producer of nuclear energy and natural gas, and the only state in the US that has a chemical facility that converts uranium yellowcake into uranium hexafluoride, a step in making nuclear fuel [5]. Illinois must continue to keep nuclear power plants running due to high elasticity of substitution, and evidently, if the plants were to shut down in the near future, the consequences would be devastating; nuclear power provides over 50% of Illinois' power across six stations [6]. Clean energy laws have kept them open, but if these laws are reversed, previous financial difficulties would make it challenging to keep the plants in operation [7].

1.1. The Renewable Energy Landscape

As climate change continues to progress, the most pressing problem facing Illinois' energy generation is the rapid increase in demand in other sectors of the economy beyond agriculture, notably in residential homes for air conditioning, which necessitates not only a greater production of renewable energy but also storage and transmission capabilities alongside

---

*Corresponding author: ayoon19@uchicago.edu
Presented: May 4, 2023

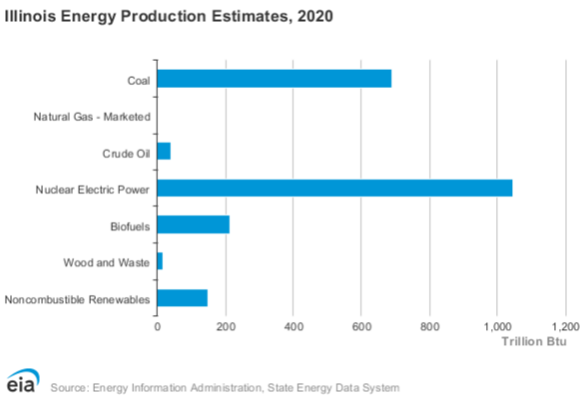

Figure 1: *Illinois Energy Production Estimates in 2020. Source: Energy Information Administration.*

to facilitate the rapid increase. The state is already facing an imminent dilemma in whether or not to classify nuclear power as renewable, which may force a rapid substitution in energy production from nuclear power to a new renewable source. Combined, Illinois needs a forward-looking energy plan and support policy. The state is seldom able to handle new renewable energy production even if additional sources are identified and constructed. In July of 2022, the power grid operator for Central and Southern Illinois approved a $10.3 billion transmission line, able to aid the production of renewable energy for 40 million homes across 8 states, including almost all of Southern Illinois [8]. These projects likely won't be completed until 2028. Even still, Illinois is a net energy exporter served by two electrical grids: ComEd, which spans the northern portion of the state, and Ameren, which serves much of the Midcontinent region. There is also a unique tradeoff between coal and natural gas in Illinois. During years when the price of natural gas is high—2021—coal plants see drastic rises in production and emissions. In 2021, coal production increased by 39% from 2020, the largest observable increase year over year, driven in large part by skyrocketing natural gas prices [9]. Notably, the restrictions passed by Governor Pritzker impose a 15-year chronological difference between coal and natural gas. Coal plants are expected to be phased out by 2030, while natural gas can remain in place as long as these plants are zero-emission by 2045 [10]. This means for 15 years a new tradeoff is likely between natural gas and renewables; should renewable prices jump, Illinois will still be heavily dependent on natural gas.

Such a tradeoff creates significant competition between renewable energy sources statewide and nationally. Illinois' heavy reliance on nuclear power has led to bearishness in the state legislature when it comes to future investment in additional non-nuclear renewable sources [11]. Nuclear lobbying and the past instances of a technical lock-in either mean that Illinois will choose to stick with nuclear energy long-term or shut down all nuclear plants and to find alternative sources in a very quick amount of time to make up for lost generation capacity. Further, the strong lobbying presence is found in coal as well—an additional competitor to solar, wind, and other more modern renewable technologies— which has continually exempted Prairie State Generating Plant from emission targets, in an attempt to keep coal prices low [12]. This is another key hurdle that renewable energy must overcome given that renewable energy competes with cheaper sources of electricity generation.

Furthermore, the EPIC (Energy Policy Institute at UChicago) forecasts a rise in energy use in Illinois as a result of warmer temps by 3%—a phenomenon common throughout the United States given rising average temperatures—although the number is disproportionately higher in wealthy areas and disproportionately lower in poorer areas due to the presence of AC [13]. States across the United States have differing abilities to cope with such demand on both the generation side and storage side. Illinois is characterized by the Energy Storage Association as having "a good opportunity with storage," yet minimal policy action has been taken; as of 2018, only 0.3 MW of storage had been deployed in the state [14]. Yet, other Midwestern states with lower renewable generation capacities have created robust cost-benefit analyses for storage. Iowa has explored a tax credit for battery storage to complement the state's wind and solar generation. This premise was key in influencing our choice of a support policy alongside renewable investment that could spur both long-term generation and storage.

In the face of weather-related stress, the energy grid's success is strongly linked to investment in such grid infrastructure; often, renewable energies are not scalable to the population with current transmission capacity, therefore necessitating additional investment from public and private entities. Therefore, a support policy is necessary to incentivize the proliferation of transmission infrastructure for renewable energy in an otherwise unprofitable scenario given the lengthy construction times that mean little economic return in the short-run.

The motivation for our study rests on the notion that without support policies alongside renewable energy investment, the United States has no economic or social incentive to curb fossil fuel production, and our over-consumption and over-extraction will perpetuate itself. Political intervention is absolutely necessary at this critical juncture, and if tax subsidies are taken seriously by local, state, and the federal governments, the country has an excellent chance at meeting binding treaty obligations in greenhouse gas emission reductions.

2. Qualitative Research

2.1. Policy Analysis

The need for regulatory pressure and assistance in the pursuit of environmental sustainability is widely documented [15]. A comprehensive analysis by Covert, Greenstone, and Knittel (2016) explains that the transition to renewable energy will not happen without economic intervention. They explore the relevant supply and demand trends. As a result of the consistent advancement of technology used to extract fossil fuels, we will not face scarcity before the environment is wrecked beyond salvage. After examining the cost trends of the highest salience renewable alternatives to fossil fuels, they conclude that none of the most viable technology will be cheap enough to overtake the demand for fossil fuels without intercession. As a result, governments are responsible for creating policies to lower the barriers to the development of green technology [16]. Since governments have been slow or weak to react to the urgency of protecting our planet, we are already heading for drastic global change. Continuing down this path would be devastating [17].

As Kirikkaleli and Adebayo (2020) demonstrate by analyzing long-run data on renewable energy consumption, the transition of major energy grids to renewable energy sources is critical to protecting the environment. They recommend that governments take affirmative action to stimulate energy sustainability [18]. Exposed by rigorous econometric testing in Bersalli, Menanteau, and El-Methni (2020), the efficacy of public policy holds up. The authors demonstrate that to achieve maximum environmental protection, a combination of public policies is necessary. Unfortunately, as we will demonstrate in the second part of this section, the political landscape in the United States provides a challenge to the comprehensive support of a renewable energy grid [19].

In American public policy, there are three primary categories of economic policies that can be used to influence individual or firm environmental impact. The first is subsidies, which give support to ecologically friendly activities. The second category includes fees, taxes, and charges which are assessed on those with a negative environmental impact. The third includes permitting systems and trading programs that help limit emissions in a variety of ways, depending on how they are set up. Legislators can also combine these three incentives in different combinations to achieve different results, depending mostly on the state of the market at the time [20].

Tax incentives are a popular and effective tool for combating climate change, but they go against the general adage of taxing the externality instead of incentivizing good behavior. Incentives should almost exclusively be used when the cost of reducing emissions is low and the emissions of the production are not too harmful. According to Bian and Xuan (2020), if a subsidy were to be implemented without these conditions, there would be little change in social welfare or emissions [21]. This means that, although they are effective, subsidies are the least economically efficient method for promoting environmental behavior in the US in the long run because converting the last holdouts to renewable energy sources will be disproportionately expensive [22]. As Arnold (2012) shows, however, the true long-term effects of subsidies such as those for R&D programs are often overlooked, providing hope for their efficacy [23]. Casey (2023) adds to the literature by demonstrating that R&D subsidies for energy efficient technology development do increase energy efficiency in the long run. Further, subsidies are the most politically feasible policy out of the three options, as we will describe later. The majority of climate bills passed in the last two administrations have taken the form of subsidies [24].

A large compendium of research demonstrates how carbon taxes are also the most effective way to increase the use of renewable energy in the US [25]. According to a recent study of corporate governance in A-list Chinese corporations, carbon penalties are more effective than subsidies. The study is further evidence that carbon taxes are effective when trying to change firm behavior [26]. However, as a regression by Wang, Liao, and Li (2021) demonstrates, it is important to note that their impact on firm behavior is reduced significantly if the carbon tax is too steep [27]. This phenomenon is described more widely as the “green paradox”, which Edenhofer and Kalkhum (2011) admit is a risk that policymakers must take into account [28].

Further, carbon taxes are regressive because they will make energy more expensive across the board, disproportionately impacting those with lower socioeconomic status. This is an effect of one of the initially attractive qualities of a carbon tax, which is a form of Pigouvian tax: it is easy to measure the impact of pollution, but difficult to accurately measure how pollution hurts any single individual due to the complex characteristics that one holds that impact his or her relationship with pollution levels. Nevertheless, everyone pollutes and those who pollute the most are also most likely to be able to pay a carbon tax [25]. As outlined in Macaluso et al. (2018), a carbon tax would also be useless if the United States passed one while our international competitors did not, unless we simultaneously passed extensive market protections [29].

The best-case scenario for the environment and environmental justice would be to institute a cap and trade system, a trading program in the third category of environmental policy. Extensive economic testing and modeling show that cap and trade systems effectively minimize the economic loss inflicted by environmental legislation. These systems also reliably help the environment, and stable output of ecological improvement is incredibly important [30]. Although several have been proposed, these systems are not politically feasible on the national level given their complexity and difficulty of implementation. The most significant risk, as described in Metcalf (2019), is that carbon caps do not remain stable because of the spillover effects of other environmental energy legislation [25].

2.2. Political Analysis

Skodvin (2007) provides a helpful framework for the analysis of the political feasibility of environmental policy. The author outlines three important factors: "1) the distribution of costs and benefits associated with environmental regulation among target groups, 2) the distribution of power among and between target groups and decision-makers, and 3) the institutional setting within which decision-making takes place." We can disregard the third, because the institutional setting of the development of US environmental policy is always the executive and legislative branches, whose rules do not change. The first two characteristics of political feasibility are highly relevant [31].

First, considering the distribution of costs and benefits associated with subsidies, taxes, and trading programs, we find that subsidies clearly make the most sense. Carbon taxes and trading programs are economically risky with adverse outcomes that hurt the most vulnerable. Subsidies are inefficient but have very little chance of households other than with the minor inflationary of introducing capital into the economy.

A comprehensive, up-to-date analysis of the policy networks of target groups and decision-makers in the US environmental policy environment is well beyond this project's scope, and no current academic work lays out the constantly changing landscape. American politics at the moment are strongly divided, with control of the Senate and the House split between the major parties. Climate change causes a cleavage, separating support for renewable energy down party lines. Republican representatives, especially those from oil-producing states, strongly oppose most climate-protection legislation. Environmental advocacy groups have a wide reach and a strong hold on congresspeople as a result of a range between large-dollar and grassroots funding. These organizations, in addition to the personal motivations of individual legislators, are preventing significant environmental action.

Subsidies for incremental progress on sustainability are most feasible in this political landscape. A tax increase, like a carbon tax, would never receive the votes in the House that it would need. A trading program would require a massive overhaul of older regulations and the institution of a large government apparatus to oversee its adoption, all of which Republican policy networks oppose. On the other hand, tax subsidies are palatable to conservatives under legislative pressure. They are politically durable as well, because industries react negatively to a decrease in government assistance.

2.3. Conclusion

As a result of the above investigation, we propose that the best solution to pursue is tax subsidy legislation. Fortunately, the Biden administration has made great strides by providing subsidies in the three landmark bills of his tenure: the Bipartisan Infrastructure Law, the Inflation Reduction Act, and the CHIPS and Science Act [32, 33, 34]. The state of Illinois similarly passed expansive environmental legislation in 2021, with several forms of subsidy support [4].

3. Quantitative Research

Our quantitative analysis will rest upon the determinations made in our qualitative analysis—specifically, that a tax incentive is the most politically feasible support policy for renewable energy investment growth. Moreover, as stated in both the introduction and the qualitative analysis, there are many factors that might affect a state-specific support policy; as such, our goal in quantitative analysis is to control for these varying factors and determine whether an incentive policy carries a significant positive association with greater renewable energy investment growth, *regardless of the state or region it is implemented in.*

Due to the lack of data, time, and our team's econometric experience, our analysis will mostly be preliminary and incomplete of any absolute result or determinate relationship. Nevertheless, our quantitative model will seek to test whether there is a significant relationship between the existence of a general tax incentive and a positive growth in renewable energy generating investment, which we hope will provide greater insight into this field and eventually facilitate accelerated development of the "greener" future that we describe in the introduction section *in any state*. We will use existing datasets and econometric tools to precisely quantify these relationships.

3.1. Data Collection and Organization

Our energy data comes from the U.S. Energy Information Administration's (EIA) State Energy Data System (SEDS), which collects a plethora of energy data for all U.S. states. Our data regarding the existence of a tax incentive come from the DSIRE database at the N.C. Clean Energy Technology Center at N.C. State University, which the Environmental Protection Agency (EPA) regards as the most reliable source of data for policies and incentives that support RE.

The SEDS estimates are categorized by data series for consumption, prices and expenditure, and production, each calculated by state (and for the United States), energy source, and sector, in their respective units, and in an annual time-series back to 1960 (1970 for prices and expenditure). We will consider all 50 states and D.C. for the years spanning 2000 to 2020. Thus, the state will be indicated by an i, where $i = 1, ...51$, and the time period will be indicated by a t, where $t = 1, ..., 21$. The EIA's SEDS data contain more than 700 variables, each equipped with a unique, five-character "MSN" code for easy identification. For the sake of our analysis, we will be considering only the following 13 MSN's (link to data in appendix):

1. **REPRB**: Renewable energy production
2. **SOTGP**: Solar thermal & photovoltaic electricity total net generation
3. **WYTCP**: Wind electricity total net generation
4. **GEEGP**: Geothermal electricity net generation
5. **BDPRP**: Biodiesel production
6. **HYTCP**: Hydroelectricity total net generation
7. **BFPRP**: Biofuel production
8. **WWPRB**: Wood and waste energy production
9. **TPOPP**: Total population
10. **GDPRX**: Real gross domestic product
11. **TETPB**: Total energy consumption per capita
12. **NGTPB**: Natural gas total consumption per capita
13. **PATPB**: Petroleum total consumption per capita

The CSV file for the complete SEDS data set listed data in long format, consisting of columns for state, year, the data series measured, and measured value; as such, the data series were stacked, all in a single column. It was necessary to our analysis that each data series have its own column, such that each could be recognized as a separate variable when run through a regression in R. We used Python and the pandas library to convert the data set to this wide format. Missing regions and shortened time series for some variables demanded additional manipulation to maintain completeness and accuracy.

DSIRE's policy data is more difficult to collect and organize, as the classification of different policy types is somewhat arbitrary. There also was no CSV file for extraction; thus, manual data collection was needed. For the purposes of simpler analysis, we considered a tax incentive on renewable energy investment as the four following policy types: a corporate tax incentive, a corporate tax deduction, a corporate tax exemption, and a commercial property tax incentive. These policies represent the tax incentive programs that most directly affect commercial and industrial renewable energy investment.

3.2. Response Variable

Bersalli, Menanteau, El-Methni (2020) give a prudent framework of a response variable that most aptly captures renewable energy investment growth. Specifically, it is pointed out that investments in new RE are not best quantified in strict dollar amounts, but in physical energy quantities (such as MW or Btu)[35]. Thus, our response variable will be defined as the net growth in renewable energy production capacity per capita:

$$\frac{REPRB_{i,t} - REPRB_{i,t-1}}{TPOPP_{i,t}} \tag{1}$$

The same equation will be used to calculate the net growth in renewable energy production capacity per capita for the specific technologies listed above (solar thermal/photovoltaic, wind, geothermal, biodiesel, hydroelectricity, biofuel, and wood & waste). The EIA data reliably distinguishes the production capacities between these technologies for all fifty states + the District of Columbia, which will allow us to analyze whether a tax incentive will have different magnitudes of impact on different technologies.

3.3. Predictor Variables

Existence of a tax subsidy (TAX_EX)

The main question we seek to explore is whether the existence of a tax subsidy in a state results in increased RE production. We regress on the following indicator variable indicating the existence of a tax subsidy in a given state in a given year:

$$1[T_{it} = t] \tag{2}$$

This variable is binary; it will equal 1 if a tax incentive exists in a given year and 0 if not. We will regress this onto the response variable discussed above, making it our primary predictor variable.

Growth in rGDP per capita

Real GDP per capita is frequently included as a regressor in similar models, under the assumption that higher-income states will be more able to undertake the startup costs associated with RE production and deploy the necessary economic incentives. The variable for year *t* is calculated as follows:

$$\frac{GDPRX_{i,t} - GDPRX_{i,t-1}}{TPOPP_{i,t}} \tag{3}$$

By including this in our regression, we account for the disparity between poorer states—like Mississippi and New Mexico—and wealthier states—like California and Massachusetts—that is often correlated with both tax policy and energy investment.

Energy consumption growth per capita

States that experience larger growth in energy consumption (which we use as a proxy for growth in energy demand) are more likely to invest in new energy production, which includes renewables. The variable is calculated as follows:

$$TETPB_{i,t} - TETPB_{i,t-1} \tag{4}$$

By including this in our regression, we want to account for the disparity between years that have high demand growth and low demand growth with this regressor.

Natural gas & petroleum consumption growth per capita

Fossil fuel demand growth could result in increased RE production as states seek to move away from fossil fuels due to the associated negative externalities, or it could make states less inclined to invest in RE production due to the large economic impact of moving away from fossil fuels. The variables are as follows:

$$NGTPB_{i,t} - NGTPB_{i,t-1} \tag{5}$$

$$PATPB_{i,t} - PATPB_{i,t-1} \tag{6}$$

for natural gas and petroleum, respectively. Moreover, it is not clear whether increased RE production, as explained in the above blurb, is merely the product of increased demand growth, and whether fossil fuel demand specifically can be separated from total growth, so we include this variable as a regressor to account for these uncertainties.

3.4. Econometric Model

To quantitatively analyze whether there is a significant relationship between the existence of a tax incentive and renewable energy production growth, we will be implementing a unit fixed effects (UFE) linear regression specification that is most appropriate for the time-series data we have. The model is as follows:

$$Y_{i,t} = \beta X_{i,t} + \alpha(S_i) + U_{i,t} \tag{7}$$

where $i = 1, \ldots, 51$ for the fifty U.S. states and the District of Columbia, and $t = 1, \ldots, 21$ for the years spanning from 2000 to 2020.

This UFE model is a pooled linear regression with the addition of a unique identity variable S_i that represents the "unit" in the data that stays constant over time, which in this case is the name of the state. The variable $X_{i,t}$ represents our combined matrix of predictor variables (known as the design matrix), $Y_{i,t}$ represents our response variable vector as described in the beginning of this section, and β represents the coefficient that predicts the relationship between $X_{i,t}$ and $Y_{i,t}$. The pooled regression model, without the inclusion of S_i, which we will also consider in our preliminary analysis, is as follows:

$$Y_{i,t} = \beta X_{i,t} + U_{i,t} \tag{8}$$

The addition of the S_i variable eliminates all variations that are not dependent on time evolution and are associated with a state. Thus, time-invariant characteristics associated with a given state (at least in the 20-year period we are considering), such as terrain, urbanization level, general climate, state-specific preferences, etc. are controlled for with the addition of this variable and will allow for more accurate analysis of the coefficients on our primary predictor variable (the existence of a tax incentive). In short, conditioning on S_i necessitates the consideration of multiple time periods in our data (since our predictor variables, X_{it}, vary with time), while the pooled regression treats each time period as simply adding new data, without the consideration that they are different time periods.

The most important part of this regression specification is the β, our vector of coefficients associated with each predictor variable. Specifically, the sign and magnitude of the coefficient associated with each predictor variable will describe the linear relationship between it and the response variable (the renewable energy capacity growth per capita, our proxy for renewable energy investment growth).

4. Results

This section presents the results of both the pooled and UFE regressions on the whole sample: 1020 observations corresponding to 51 states over 20 years. We considered simple regressions first, where our only predictor variable was the existence of a tax incentive. We subsequently considered regression specifications with the addition of covariates as described in the predictor variables section.

4.1. General Results

Pooled Regression

Table 1 summarizes both the simple regression and the covariate regression for the two regression specifications we considered. First, we see that the resulting coefficient for the pooled regression, both without and with covariates, is positive and the p-value shows statistical significance for our primary predictor variable, the existence of a tax incentive. Such a result indicates that there is a statistically significant positive correlation between a tax subsidy and renewable energy production capacity growth per capita, at least when considering the entirety of the EIA and DSIRE data.

After controlling for additional predictor variables, we see that renewable energy investment growth per capita exhibits a statistically significant positive linear relationship with energy demand and a negative linear relationship with natural gas/petroleum consumption. Both results make intuitive sense. First, we would expect that with an increase in energy demand per capita, legislators would need to support energy investment to meet that rising demand; presumably, a portion of that support would come from the RE sector. Second, the negative relationship between fossil fuel consumption and greater RE capacity growth suggests that if more RE is available to consume, there is less fossil fuel energy being consumed.

Unit Fixed-Effects Regression (UFE)

However, a pooled regression analysis is tentative at best. As stated in the description of our econometric model, a pooled regression does not account for the time-invariant state characteristics that may covary with the linear relationship between renewable energy investment growth and tax incentive existence. A unit fixed-effects regression thus controls out for these state-specific characteristics (such as terrain, urbanization, annual climate, unobserved cultural characteristics, etc.) that do not vary with time and generates a cleaner, more direct linear relationship between tax incentives and RE investment growth and allows us to analyze the state-independent association between our two variables of interest.

In the simple UFE regression with no covariates, we see that the relationship between the existence of a tax incentive and renewable energy investment growth per capita is positive, but not statistically significant. Once we add our covariates, however, we see that the linear relationships become statistically significant, and the magnitude of the relationship between the tax incentive and renewable energy production growth per capita increases. This suggests a relationship that is encouraging and intuitive: in an analysis that is state-independent and accounts for confounding factors like general energy demand and economic health, we see that a tax incentive policy does indeed exhibit a significant positive linear relationship with the amount of growth in renewable energy investment.

4.2. Technology-Specific Results

Now, we observe our results for specific renewable energy technologies. We recognize that a tax incentive may not carry an equal relationship with all technologies equally. Safer, more researched technologies with a history of stable returns, like solar and wind, will most likely have a more significant relationship with a tax incentive than with more state-specific, riskier investments like hydroelectricity or biofuels, as legislators have greater justifications for supporting the former. We considered the UFE regressions with all of our covariates from our general regressions above, with sample size remaining constant ($n = 1020$). Table 2 formats these regression results. Figure 2 exhibits the average greenhouse gas emissions for energy sources, which becomes interesting when considering the relationship between such emissions and the effectiveness of a tax incentive for specific technologies.

Solar Thermal and Photovoltaic Energy

We first look at the most popular RE investment, solar thermal and photovoltaic production. We can think of this response variable as one of the two "most interesting" (along with wind energy) for large infrastructure funds and institutional investors, as solar farms and wind farms are among the most invested RE technologies in the market today, exhibiting near-similar returns to regular energy investments. It is thus interesting to clarify the relationship between this growth in solar capacity and the tax incentives that aim to increase such growth.

Table 2’s first column shows the coefficients describing this linear relationship. The coefficient is positive and *very* statistically significant; a p-value of below 0.01 (indicated by the triple asterisk) means

Table 1: *Coefficients for Total Renewable Energy Growth/Capita (Standard Errors in Parentheses)*

	Dependent variable			
	Renewable Energy Capacity Growth Per Capita (Million Btu)			
	Pooled Regression		*Unit Fixed-Effects*	
	Simple (1)	With Covariates (2)	Simple (3)	With Covariates (4)
Tax Incentive	0.927**	0.877**	0.860	1.227**
	(0.466)	(0.439)	(0.645)	(0.618)
rGDP		−0.236		−0.336**
		(0.157)		(0.153)
Energy Demand		0.285***		0.252***
		(0.025)		(0.025)
NG Consumption		−0.214***		−0.211***
		(0.032)		(0.031)
Petr. Consumption		−0.274***		−0.243***
		(0.038)		(0.037)
Intercept	0.803**	1.500***		
	(0.340)	(0.338)		
Observations	1,020	1,020	1,020	1,020
R^2	0.004	0.121	0.002	0.103
Note:			*p<0.1; **p<0.05; ***p<0.01	

Table 2: *Coefficients for Technology-Specific Renewable Energy Growth/Capita (Standard Errors in Parentheses)*

	Dependent variable					
Unit Fixed-Effects	Solar/PV (MW) (1)	Wind (MW) (2)	Geothermal (MW) (3)	Hydroelectricity (MW) (4)	Biofuels (Barrels) (5)	Wood/Waste (Million Btu) (6)
Tax Incentive	0.033***	0.088***	0.003**	0.094**	−0.136**	0.131
	(0.004)	(0.027)	(0.001)	(0.046)	(0.053)	(0.190)
rGDP	−0.0001	−0.028***	0.0002	0.005	−0.016	−0.029
	(0.001)	(0.007)	(0.0003)	(0.012)	(0.013)	(0.047)
Energy Demand	0.0002	−0.002	−0.00001	0.009***	0.015***	0.084***
	(0.0001)	(0.001)	(0.00005)	(0.002)	(0.002)	(0.008)
NG Consumption	−0.0003	0.0003	0.00004	−0.011***	−0.008***	−0.049***
	(0.0002)	(0.001)	(0.0001)	(0.002)	(0.003)	(0.010)
Petr. Consumption	−0.0004	0.002	0.00003	−0.007***	−0.016***	−0.089***
	(0.0002)	(0.002)	(0.0001)	(0.003)	(0.003)	(0.011)
Observations	1,020	1,020	1,020	1,020	1,020	1,020
R^2	0.080	0.042	0.007	0.034	0.064	0.123
Note:					*p<0.1; **p<0.05; ***p<0.01	

that there is a less than a 1% probability that this relationship is due to chance. The magnitude of the relationship (0.033 MW/capita) is somewhat small—thus, given the statistical strength, results indicate a strong, but not necessarily large, relationship between the two variables. In other words, such a result suggests that, all else equal, tax incentives are associated with a more statistically significant relationship with solar energy generation & investment growth than with RE investment in general, which further suggests the low-risk nature of solar investment.

Wind Energy

Similar to the relationship between solar energy capacity growth and tax incentives, wind energy generation growth exhibits a very statistically significant linear relationship with tax incentive existence as shown in column (2) of Table 2. The magnitude of the relationship is even greater than solar power, suggesting that the tax incentive has a greater positive relationship with wind power than solar power. Such results are intuitive once again, since after controlling for state-dependence and other potential confounding factors, wind electricity generation growth is associated with incentive factors due to its mainstream position in the general RE investment landscape.

It must also be noted that wind turbines are more effective at converting energy than solar panels. Thus, a policy incentivizing renewable energy investment may induce investors to lean towards the least risky, most efficient investment choice, which in this case, seems to be wind energy. This may explain the larger magnitude of the relationship.

Geothermal Energy

For geothermal energy, the results indicate another positive linear relationship. Specifically, a positive and statistically significant (although less significant than both solar and wind electricity) correlation between a tax incentive and geothermal energy generation growth per capita exists, as shown in column (3) of Table 2. It is important to note, however, that the small magnitude of the coefficient—this may be due to the size of the geothermal energy sector. Very few states produce geothermal energy, and thus the absolute linear relationship of a tax incentive on geothermal energy growth seem to be much smaller (albeit still positive) compare to the two previous technologies. As such, the lack of plentiful investment opportunities may push firms to consider solar and wind before geothermal plants, contributing to the smaller and less statistically significant association between geothermal energy generation growth and incentivizing policy.

Hydroelectricity

Hydroelectricity exhibits a less statistically significant linear relationship between tax incentives and generation growth than solar, wind, and geothermal energy, but it is nonetheless still positive and statistically significant against a 0.05 p-value as shown in column (4) of Table 2.

We note that the magnitude of the relationship is greater than any of the aforementioned technologies—this may be due to states that produce hydroelectricity specifically targeting hydro plants with their tax incentives. It also may be that water flux in hydroelectricity sources is more predictable than the weather, which solar and wind energy both depend on, making the former a preferred investment in areas that carry a tax incentive *and* are conducive to hydroelectric power plant construction. This would contribute to explaining the larger association between the two variables.

Biofuels

Here, we observe an interesting relationship. The linear relationship between tax incentives and the production growth of biofuels is statistically significant; however, the two are inversely associated. This means that all else equal, if there is a tax incentive in a given state, biofuel production growth decreases. The result seems counterintuitive, but on further analysis, may make sense.

First, we may extrapolate that tax subsidies on renewable energy introduce new incentives that actually drive economic agents away from biofuels and towards other forms of renewable energy. Thus, if a tax incentive exists, investors may want to gravitate towards less risky and more profitable renewable energy sources, such as the ones above. They also may gravitate towards such investments if the amount of CO2 emissions avoided has a direct imapct on the amount of money gained by the tax incentive. As shown in Figure 2, Biomass (which is used to produce biofuels) emit greater levels of greenhouse gases than solar, wind, or geothermal energy, and thus, may not be incentivized for production in such tax incentive policies. Second, it may also be the case that tax subsidies do not include biofuels, and thus tax incentives would induce a movement away from biofuel energy sources as investment would not be incentivized. Again, this would make sense, as legislators usually target sources of renewable energy that are both environmentally friendly and efficient to meet growing demand and sustainability requirements. Biofuels are a renewable energy, but not as effective of a technology as some of the previous sources.

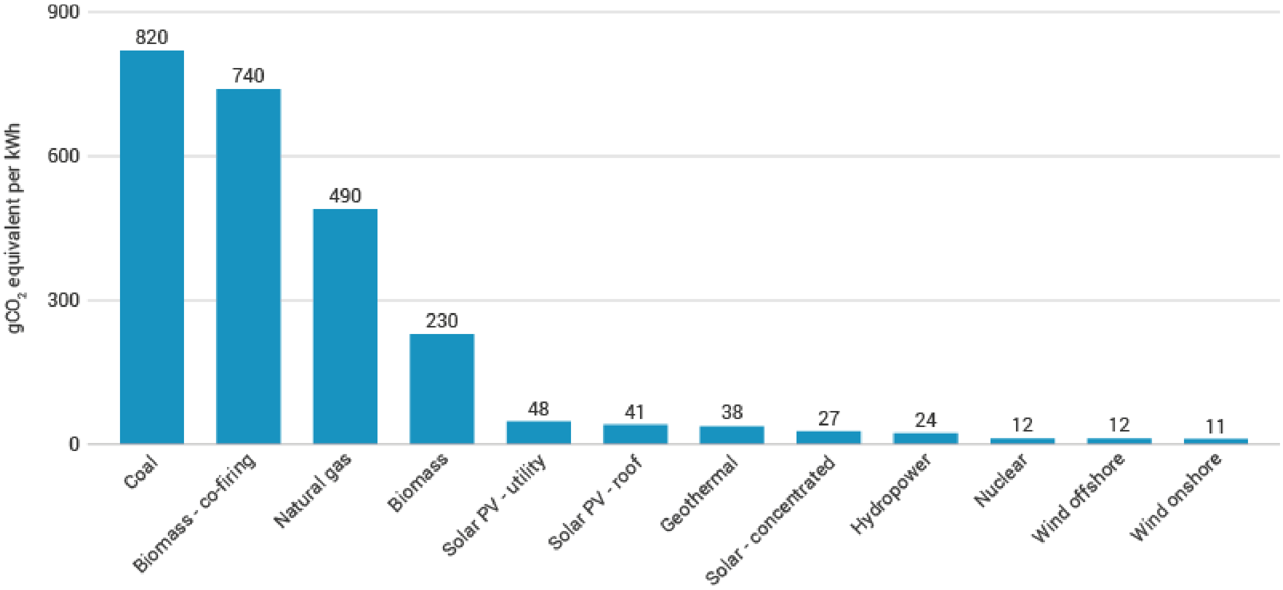

Figure 2: *Average greenhouse gas emissions by energy source, Source: World Nuclear Association.*

Wood & Waste Energy

We see a non-statistically significant relationship between wood/waste energy production growth and the imposition of a tax incentive. The standard error number (in parentheses below the coefficient) is greater than the coefficient itself, and this indicates that the linear relationship is not significant enough to even make any speculative conclusions on. This result shows that tax incentives may not be associated with wood/waste energy often, and that any fluctuations in production are not attributable to the association with a tax incentive. Many tax incentive bills do not include wood/waste energy as a target in growth aspirations, which may explain the lack of a significant relationship between the two variables.

4.3. Conclusion

Our preliminary econometric analysis shows that there are significant associations between renewable energy investment growth (measured by our response variable of production growth per capita) and tax incentives, especially after controlling for some potentially confounding variables. It is important to note here that we could not control for all such covariates due to lack of data and a lack of deeper analysis on our team's part. We do not yet possess the econometric knowledge to impose more rigorous restrictions on our regression models that would enable us to more clearly isolate the linear relationships present (we will discuss the potential next research steps in the next section).

After splitting up total renewable energy investment growth into particular technologies, we observe that the intuitively expected result—namely, that safer, more environmentally friendly, and profitable investments like solar, wind, and hydroelectricity—have a much stronger linear association with the tax incentive policy than of other, less-popular, and less environmentally friendly RE sources, like biofuels and waste energy. As such, our analysis describes the renewable energy landscape as one that needs to take both the perspective of the investor and the broader climate implications into account, ensuring that both are aligned when implementing policies that aim to reduce carbon emissions and inch us towards a greener future.

5. Discussion

We will now discuss the broader implications of our quantitative analysis. Specifically, we discuss three topics: weaknesses in our quantitative analysis, causality, and further statistical analysis.

5.1. Weaknesses

The main weakness in our research comes from our lack of experience and thus, a lack of rigor. While the qualitative analysis and the econometric model used previous research as a foundation and attempted to apply it in the most prudent manner possible, we recognize that there might be errors and shortcomings within our application of the model that we did not correct, due to ignorance and lack of knowledge.

Another shortcoming is that we did not differentiate between types of tax incentives. We recognize that certain tax policies, such as a corporate tax incentive or deduction, may be more effective than a property tax exemption for generating investment growth in renewable energy. Our main regressor simply accounted for the *existence* of a tax incentive, rather than accounting for the different structures and types of policy that most likely affects renewable energy investment growth in different ways. Furthermore, the intensity of the policy, such as the dollar amount subsidized or deducted from a firm's tax bill, most likely affects our response variable as well, yet we do not account for these differences. Lastly, it is likely that the existence of a tax incentive is accompanied by many other policy changes in a given state, due to the dynamics of the legislature in a given year (i.e. if a legislature is controlled by a certain party, they may pass bills that may affect renewable energy growth), but we do not account for these other variables or policies. Such additions may change the conclusions of our study. Nonetheless, as mentioned, our research aims to serve as a starting point for future research, rather than being a determinate source of evidence for policy action.

Apart from the two discussed topics of concern, there are some statistical shortcomings. Our results show very statistically significant relationships that exhibit small standard errors and strong, encouraging relationships between RE growth and tax incentive existence. These small errors and strong relationships are due to the small amount of variance in the data: the set of coefficients that measure the relationship between per capita renewable energy investment growth numbers and tax incentive existence are not very spread out compared to their average value. This may seem like a desirable result, but we look at them with a healthy amount of skepticism.

Specifically, we recognize the *bias-variance tradeoff* that exists in statistics, which our study is almost definitely subject to. This concept states that the variance of any parameter that is estimated with the use of statistical tools (like the coefficients, β, which aim to predict the linear relationship between our predictor variables and response variable) can be reduced with an increase in bias. Bias is the difference between our estimated parameter's expected value and its true value. Thus, we suspect that while our results show low variance, it may contain high bias towards favorable results due to confounding variables, imperfect regression application, errors in implementing the data analysis, and/or a host of other factors.

We also have been careful throughout the quantitative analysis section to avoid using causal language. This was a deliberate choice—not only due to the fact that our analysis is only preliminary, but due to the broader implications of what a linear regression framework enables us to say. Specifically, any regression specification, regardless of the type, exhibits a *relationship*, rather than enabling us to assign *causality* to any of the predictor variables. Thus, we can analyze and speculate on associations and why those relationships may exist between variables, but we cannot attribute any certain causal argument to the results of this specific study.

5.2. Next Steps: Causality & Statistical Analysis

Causality

To be able to demonstrate a specific and precise causal relationship between the tax incentive and renewable energy investment growth, we would need to undertake a further study established on a common trends approach that implements a difference-in-differences (DID) argument. Specifically, we would need to determine whether a state or region that *does* have a tax incentive experienced an increase compared to when it *did not* have a tax incentive, subsequently comparing this value to its *counterfactual*: if the region did not implement a tax incentive, what would have been the outcome, all else equal?

Obviously, we cannot observe this counterfactual, as it has not actually happened. This is where a DID argument opens up the possibility of assigning causality: it can compare changes in outcomes between states who were affected by a treatment variable (i.e. the passing of a tax incentive for RE) to changes in outcome for states unaffected by that same treatment variable. Such an argument rests on a common trends assumption—that if the treatment had not occurred, the changes observed in the states affected by that treatment would have been the same as the states who were unaffected. This argument would open up the possibility of deeper causal relationships, and a study of such nature with differentiated policy data (as discussed in the Weaknesses section) would provide far more insight onto not only the linear relationship between policy and RE growth but also the intensity of the causal effect. We see this as the logical next analysis to carry out.

Residuals & Variance

Furthermore, to reduce bias as mentioned in the previous subsection and get asymptotically closer to the true value of the relationship between RE investment growth and the implementation of a tax incentive, further analysis would warrant more aggressive examination of the data. This may include the steps outlined above in the previous two subsections. It may also include an analysis of the residuals, $U_{i,t}$, to determine whether heteroskedasticity or homoskedasticity exists—less technically, whether the residuals in the regression does not covary with the value of our predictor variables and thus indicates that the variables carry finite variance.

The regressions we ran as a part of our research assume homoskedasticity, which is a very strong assumption and often not correct. This would lead us to overestimate the prediction as well as have biased standard errors. Thus, further analysis of the variance and residuals present in our data may lend greater insight into the true relationship between RE investment growth and tax incentive policies. There are many factors that may induce non-constant variance both across predictor variables and within a single predictor variable. Stronger statistical analyses like these can sketch a much clearer and precise picture of the relationships present, establishing stronger foundations for future studies and research.

5.3. Acknowledgements

We would like to thank our partner for this project, Professor Po-Chun Hsu (University of Chicago, Pritzker School of Molecular Engineering), along with Professor Esteban Rossi-Hansberg (University of Chicago, Kenneth C. Griffin Department of Economics) and Professor Alexander Torgovitsky (University of Chicago, Kenneth C. Griffin Department of Economics) for their guidance throughout this project. Without their generous advice and direction, this project would not have come to fruition, and our team is indebted to them for their willingness to actively support our research endeavors.

We would also like to thank Tobias Abelmann (University of Chicago, Class of 2024) for his contribution in analyzing and discussing the results of our regressions. His input and insight facilitated a more in-depth consideration of our quantitative results that contributed greatly to our results & discussion sections.

Lastly, we would like to thank the board members of the Paul Douglas Institute, especially the VPs of Research, Jason Jacobs and Arushi Bansal, for guiding our team throughout this research project. Without their administrative help and support, we doubt that our team could have run as effectively as it did.

5.4. Appendix

The EIA's SEDS data can be found here: www.eia.gov/state/seds/seds-data-complete.php?sid=US.

The DSIRE policy data can be found here: programs.dsireusa.org/system/program.

References

[1] Alexander Saier. *Climate Plans Remain Insufficient: More Ambitious Action Needed Now*. Oct. 2022. url: https://unfccc.int/news/climate-plans-remain-insufficient-more-ambitious-action-needed-now.

[2] *Path to 100 Coalition Secures 50% Renewable Energy Standard for Illinois*. Sept. 2021. url: https://www.seia.org/news/path-100-coalition-secures-50-renewable-energy-standard-illinois.

[3] Emma Foehringer Merchant. *Illinois Approves Path to 25% Renewable Energy by 2025*. Apr. 2018. url: https://www.greentechmedia.com/articles/read/illinois-approves-path-to-a-quarter-renewable-resources-by-2025.

[4] *Gov. Pritzker Signs Transformative Legislation Establishing Illinois as a National Leader on Climate Action*. Sept. 2021. url: https://www.illinois.gov/news/press-release.23893.html.

[5] *Uranium Conversion*. Dec. 2020. url: https://www.nrc.gov/materials/fuel-cycle-fac/ur-conversion.html.

[6] *Illinois State Profile and Energy Estimates*. url: https://www.eia.gov/state/?sid=IL.

[7] Tyson Brown and Slade Johnson. *Two nuclear power plants in northern Illinois reversed plans to retire early*. Oct. 2018. url: https://www.eia.gov/todayinenergy/detail.php?id=50136#.

[8] Elizabeth. *$10.3B renewable energy transmission project long-term response to capacity shortage*. July 2022. url: https://www.citizensutilityboard.org/blog/2022/07/27/10-3b-renewable-energy-transmission-project-long-term-response-to-capacity-shortage/.

[9] Tyler Hodge. *U.S. coal-fired generation declining after brief rise last year*. Oct. 2022. url: https://www.eia.gov/todayinenergy/detail.php?id=54419.

[10] Kari Lydersen. *As Illinois phases out fossil fuels, law offers support to transition workers*. Sept. 2021. url: https://energynews.us/2021/09/22/as-illinois-phases-out-fossil-fuels-law-offers-support-to-transition-workers/.

[11] KHQA Staff. *Illinois Senate passes bill to lift ban on nuclear power construction*. Mar. 2023. url: `https://khqa.com/news/local/illinois-senate-passes-bill-to-lift-ban-on-nuclear-power-construction`.

[12] Kari Lydersen. *Troubled Illinois coal plant never received an operating permit, ran 'illegally' for over a decade, lawsuit says*. Mar. 2023. url: `https://energynews.us/2023/03/22/troubled-illinois-coal-plant-never-received-an-operating-permit-ran-illegally-for-over-a-decade-lawsuit-says/`.

[13] Molly Taft. *Rising Temperatures Will Change Air Conditioning Use—But Not How You Might Expect*. Oct. 2021. url: `https://gizmodo.com/rising-temperatures-will-change-air-conditioning-use-bu-1847853975`.

[14] *Illinois Energy Storage Policy*. Sept. 2021. url: `https://www.sandia.gov/app/uploads/sites/163/2021/09/GESDB_IllinoisStorageSummary_v2.pdf`.

[15] Hu Tau et al. "Environmental Finance: An Interdisciplinary Review". In: *Technological Forecasting Social Change* 179.3 (June 2022), pp. 901–14. doi: `10.1016/j.techfore.2022.121639`.

[16] Thomas Covert et al. "Will We Ever Stop Using Fossil Fuels?" In: *Journal of Economic Perspectives* 30.1 (2016), pp. 117–38. doi: `10.1257/jep.30.1.117`.

[17] Hoesung Lee (Chair). *Synthesis Report of the Sixth Assessment Report*. 2023. url: `https://www.ipcc.ch/ar6-syr/`.

[18] Dervis Kirikkaleli and Tomiwa Sunday Adebayo. "Do Renewable Energy Consumption and Financial Development Matter for Environmental Sustainability? New Global Evidence". In: *Sustainable Development* 29.3 (2020), pp. 583–94. doi: `10.1002/sd.2159`.

[19] Germán Bersalli et al. "Renewable Energy Policy Effectiveness: A Panel Data Analysis across Europe and Latin America". In: *Renewable and Sustainable Energy Reviews* 133 (Nov. 2020). doi: `10.1016/j.rser.2020.110351`.

[20] *Economic Incentives*. Sept. 2022. url: `https://www.epa.gov/environmental-economics/economic-incentives`.

[21] Junsong Bian and Xuan Zhao. "Tax or Subsidy? an Analysis of Environmental Policies in Supply Chains with Retail Competition". In: *European Journal of Operational Research* 283.3 (June 2020), pp. 901–14. doi: `10.1016/j.ejor.2019.11.052`.

[22] *Climate Change: Fossil Fuel Subsidies*. Sept. 2019. url: `https://www.imf.org/en/Topics/climate-change/energy-subsidies`.

[23] Erik Arnold. "Understanding long-term impacts of RD funding: The EU framework programme". In: *Research Evaluation* 21.5 (Dec. 2012), pp. 332–343. doi: `10.1093/reseval/rvs025`.

[24] Gregory Casey. "Energy Efficiency and Directed Technical Change: Implications for Climate Change Mitigation". In: *The Review of Economic Studies* (Mar. 2023). doi: `10.1093/restud/rdad001`.

[25] Gilbert E. Metcalf. "On the Economics of a Carbon Tax for the United States". In: *Brookings Papers on Economic Activity* (2019), pp. 405–84. doi: `10.1353/eca.2019.0005`.

[26] Ling He et al. "Penalties vs. Subsidies: A Study on Which Is Better to Promote Corporate Environmental Governance". In: *Frontiers in Environmental Science* 10 (June 2022). doi: `10.3389/fenvs.2022.859591`.

[27] Gaoke Liao Mengxin Wang and Yanling Li. "The Relationship between Environmental Regulation, Pollution and Corporate Environmental Responsibility". In: *International Journal of Environmental Research and Public Health* 18.15 (July 2021). doi: `110.3390/ijerph18158018`.

[28] Ottmar Edenhofer and Matthias Kalkuhl. "When Do Increasing Carbon Taxes Accelerate Global Warming? A Note On the Green Paradox". In: *Energy Policy* 39.4 (2011), pp. 2208–2212. doi: `10.1016/j.enpol.2011.01.020`.

[29] Nick Macaluso et al. "The Impact of Carbon Taxation and Revenue Recycling on U.S. Industries". In: *Climate Change Economics* 9.1 (2018). doi: `10.1142/s2010007818400055`.

[30] Richard Schmalensee and Robert N. Stavins. "Lessons Learned from Three Decades of Experience with Cap and Trade". In: *Review of Environmental Economics and Policy* 11.1 (2017), pp. 59–79. doi: `10.1093/reep/rew017`.

[31] Tora Skodvin. "Exploring the Notion of Political Feasibility in Environmental Policy". In: *Cicero Working Papers* (2007).

[32] Justin Badlam et al. *Navigating the Complexity of the Bipartisan Infrastructure Law*. url: `https://www.mckinsey.com/industries/public-and-social-sector/our-insights/navigating-the-complexity-of-the-bipartisan-infrastructure-law`.

[33] Justin Badlam et al. *The Chips and Science Act: Here's What's in It*. url: `https://www.mckinsey.com/industries/public-and-social-sector/our-insights/the-chips-and-science-act-heres-whats-in-it`.

[34] Adi Kumar et al. *The Inflation Reduction Act: Here's What's in It*. url: `https://www.mckinsey.com/industries/public-and-social-sector/our-insights/the-inflation-reduction-act-heres-whats-in-it.`.

[35] Philippe Menanteau Germán Bersalli and Jonathan El-Methni. "Renewable energy policy effectiveness: A panel data analysis across Europe and Latin America". In: *Renewable and Sustainable Energy Reviews* 133.1 (2020). doi: `10.1016/j.rser.2020.110351`.