THE ROLE OF FEDERAL TAX CREDITS IN U.S. SOLAR INDUSTRY GROWTH

A Thesis
submitted to the Faculty of the
Graduate School of Arts and Sciences
of Georgetown University
in partial fulfillment of the requirements for the
degree of
Master of Public Policy
in Public Policy

By

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Washington, DC
April 12, 2018

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ABSTRACT

Tremendous growth has been observed in the U.S. solar industry over the last two decades. While technological improvements and falling costs have played large roles, a federal policy that provided a 30 percent tax credit toward solar photovoltaic (PV) installations is commonly touted as the critical driver in facilitating this growth. The policy is known as the "Business Energy Investment Tax Credit" or "ITC". The effect of various federal policies on the energy sector has been documented by researchers. Yet, the body of literature analyzing just one policy (the ITC) on one energy source (solar PV) is less robust. Additionally, research that does exist on the ITC is sometimes truncated in terms of years of analysis and may not include the entire history of the policy. This paper uses fixed effects models and state-year level data from the National Renewable Energy Laboratory, the U.S. Energy Information Agency, and other sources to analyze the extent to which the ITC has contributed to indicators of growth in solar PV from 1997-2015; roughly ten years of the policy's implementation and ten years prior for comparison. Results indicate the tax credit has had a positive and strikingly robust effect on solar PV growth even after the addition of extensive controls. Policy implications discussed include the need for continuation of the credit if solar PV's barriers to entry in the energy market are to retain parity with other more "traditional" sources, potential negative effects of the ITC on other energy sources, and impacts of the ITC on secondary outcomes including the price of electricity, CO_2 emissions, and global climate goals.

ACKNOWLEDGEMENTS

The writing of this thesis would not have been possible if not for the help and support from my incredible friends, family, and mentors. Graduate school tested me on many levels and I would not have gotten through it without each of you. This thesis is dedicated to you and to all those in my family who showed me the value of education, who pursued advanced degrees while raising small children – in particular my Mother who as a single mom raised my sisters and me while pursuing her PhD, a feat for which I now have new appreciation. To all those Craigs and Hackmans who came before me and paved the way for me to have this life-changing opportunity at a school I never dreamed I would attend as a rebellious Midwestern youth.
I am so grateful to all of you. From the bottom of my heart, thank you.

Finally, a special thanks to my thesis advisor Dr. Andreas Kern for his unwavering optimism, patience with my many questions, and for steering me through this strange, initially-horrible-but-eventually-enlightening process of research and discovery.

Sincerely,
Charles Hackman

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I. INTRODUCTION

Many stakeholders claim that passage of the 30 percent "Business Energy Investment Tax Credit" (ITC) in 2005 was critical in the competitive development of the U.S. solar industry (especially over the last decade).[1234] They claim the credit has reduced costs, created hundreds of thousands of jobs,[5] and facilitated the rapid growth of a domestic industry that also provides secondary benefits to society that include reducing pollution by displacing "dirtier" and more "traditional" fossil fuel energy sources. These benefits should lead to continued full congressional re-authorization of the policy, they argue. However, the history of the credit has been one of uncertainty and political disagreement. Currently, the ITC is scheduled for a graduated phase down (yearly percentage reduction) that will result in its complete elimination by 2022 unless additional policy action is taken.

Understanding the impact of the ITC is useful for stakeholders interested in continuing the policy in coming years. Furthermore, evaluating the effectiveness of any federal program is useful for the broader public in ensuring the federal government is allocating resources wisely and toward policies that impact society in large ways – such as how our domestic electricity is produced. For these reasons, this thesis explores the relationship between the ITC and indicators of "growth" within the solar industry.

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[1] ITC analysis from the Solar Energy Industries Association can be accessed through (https://www.seia.org/research-resources/solar-itc-impact-analysis)

[2] ITC analysis from the Pew Charitable Trusts can be accessed through (http://www.pewtrusts.org/en/research-and-analysis/fact-sheets/2015/02/federal-programs-enable-unprecedented-solar-power-deployment).

[3] ITC analysis from the U.S. Department of Energy can be accessed through (https://www.energy.gov/sites/prod/files/2016/12/f34/Leveraging_Federal_Renewable_Energy_Tax_Credits_Final.pdf).

[4] ITC analysis from McKinsey & Company can be accessed through (https://www.mckinsey.com/client_service/sustainability/latest_thinking/~/media/5E847C563A734F148B5F3A6EFBD46E39.ashx).

[5] In 2017, the solar industry supported 374,000 jobs nationwide, according to a report on Energy and Employment by the U.S. Department of Energy, which can be accessed through(https://www.energy.gov/sites/prod/files/2017/01/f34/2017%20US%20Energy%20and%20Jobs%20Report_0.pdf).

My primary variable of interest quantifying this growth is the sum of annual installed solar photovoltaic (PV) capacity, measured in KW, per state since the policy's implementation in 2006. This is measured from grid-connected, residential and non-residential solar PV systems. As other indicators of growth, I also look at total number of new solar PV installations reported annually per state, annual solar energy consumption for electric power generation, as well as changes in price and cost factors within the industry over time. Finally, I evaluate the ITC's impact on secondary outcomes including: carbon intensity of the energy supply, per capita energy-related carbon dioxide (CO2) emissions, and impacts on other energy sources.

My primary hypothesis is that there is a positive association between the introduction of the ITC – or, more accurately, the increase of the ITC from 10 percent before 2005 to 30 percent after – and installed solar PV capacity (in KW/yr). Due to the nature of the policy – a dollar-for-dollar reduction in the income taxes that a person or company claiming the credit would otherwise pay the federal government – it is likely that there would be a positive effect on installed solar PV capacity during the years in my analysis when the 30 percent credit was available (2006-2015) compared to the years in my analysis during which the credit was not available or was lower (1997-2005). If the ITC succeeded in lowering barriers to entry, more solar PV installers might have decided to enter the market post-2005 and compete in what they might have predicted would be an emerging new energy industry with large future growth potential.

A secondary hypothesis that I will consider in more detail, for the purposes of evaluating the policy implications of continuing the ITC, is that there have been observed benefits in CO2 reduction due to the ITC. If my research shows an observed positive effect between the ITC and growth in solar energy then it is plausible a positive relationship between the ITC and CO2 emissions reductions could also exist. Implications of the latter relationship on local, federal, and international policy are wide ranging and are expanded upon throughout this paper.

I test my main hypothesis primarily using data from the "Open PV Project," a collaboration between the Lawrence Berkeley National Laboratory and the National Renewable Energy Laboratory – both of the U.S. Department of Energy. I chose to look at state-annual level data of solar PV from 1997-2015 because this time span includes roughly 10 years of data prior to the ITC's increase to 30 percent and roughly 10 years after. To control for potential confounding variables that I may pick up through state and time fixed effects, I use additional data on employment/unemployment, GDP, and other related energy-sector data.

My baseline model and simple controls produce a positive and highly significant coefficient on my variable representing the investment tax credit which indicates a clear relationship between the ITC post-2005 and increased installed solar PV capacity. I test the robustness of this initial result through extensive further modeling that introduces additional controls for various indicators of energy-sector consumption and price, for locations that may have been more conducive to solar, and for state or local policies that may have also incentivized solar growth. Despite these controls, all models continue to show a strikingly robust effect between the ITC and solar PV growth between 2006-2015. My analysis also shows a positive and robust relationship between the ITC and other growth indicators, including: total number of solar installations per year, total reported annual solar PV generation per year, and total solar energy consumed. Finally, my results find a significant relationship between the ITC and several indicators of CO2 emissions reductions.

There are three main policy implications from my analysis. First, the increase of the tax credit from 10 percent to 30 percent successfully reduced the barriers to entry in the energy sector which enabled more firms to enter the market and provide higher levels of solar PV installations. Second, installed capacity grew at a higher rate from 2006-2015 compared to 1997-2005 (trends to this regard I have re-created directly from my data). Third, if the tax credit expires, yearly installed solar PV capacity could be reduced which could have secondary implications regarding commitments the United States has made to reduce our CO2 emissions. These commitments at the macro level include the international Paris climate agreement and more locally include state renewable energy portfolio standards as well as municipal-level policies. A thorough analysis of these implications and policy recommendations are detailed in section VI. "Summary of Findings".

II. BACKGROUND

Federal energy tax policy in the United States began in 1918 and was historically designed to promote oil, coal, and natural gas production. A century later, the International Monetary Fund calculates the U.S. still has combined post-tax annual subsidies of $349 billion toward the oil industry, $178 billion toward coal, and $78 billion toward natural gas. The U.S. is the second largest subsidizer of domestic energy production in the world, behind China.[6]

The first iteration of the Business Investment Tax Credit was in 1962. The Revenue Act of 1962 (P.L. 87-834) provided a credit to companies of 7 percent of their capital spending. This was passed to help drive economic growth and incentivize capital investment in multiple sectors including communications, transportation, and energy.[7]

In the 1970's, the environmental movement and two energy crises helped open federal energy tax policy to alternative/renewable energy sources. Incentives for renewable energy (RE)

[6] As of 2015. IMF analysis can be accessed through (https://www.imf.org/en/News/Articles/2015/09/28/04/53/sonew070215a).
[7] Deloitte analysis on history of federal energy tax credits can be accessed through (https://www2.deloitte.com/content/dam/Deloitte/us/Documents/Tax/us-tax-wnt-irs-and-treasury-release-notice-on -new-energy-credits-regulations.pdf).

investment were first introduced in 1978 under the Energy Tax Act (P.L. 95-618). The law increased the ITC to 10 percent for businesses that invested in solar, wind, geothermal, and other alternative/RE sources as defined by the law.[8]

During the Reagan Administration, there was an attempt to reform, streamline, and simplify U.S. domestic tax policy. The body of tax laws -- known as the Internal Revenue Code (IRC) – went through an overhaul under the Tax Reform Act of 1986 (P.L. 99-514).[9] The Act repealed most of the ITC for other sectors but extended it for energy investment in solar, geothermal, and other alternative/RE sources under section 48 of the IRC.[10] In 1992, the Energy Policy Act (P.L. 102-486) permanently extended the ITC for solar and geothermal under IRC section 48.[11]

In 2005, the Energy Policy Act was rewritten with the title ''*an Act to ensure jobs for our future with secure, affordable, and reliable energy*" and passed into law as P.L. 109-58."[12] The five-hundred-page bill comprehensively addressed many aspects of U.S. energy production and uses from all energy producing sectors, transportation, included components on energy efficiency, science, research and development, climate change and more. The Act also included a section on energy policy tax incentives which amended the IRC and expanded the list of renewable energy technologies eligible for the ITC.

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[8] Deloitte analysis on history of federal energy tax credits can be accessed through (https://www2.deloitte.com/content/dam/Deloitte/us/Documents/Tax/us-tax-wnt-irs-and-treasury-release-notice-on -new-energy-credits-regulations.pdf).
[9] Joint Committee on Taxation analysis of the Tax Reform Act of 1986 can be accessed through (https://bit.ly/2Hbzwta).
[10] The Tax Reform Act of 1986 can be accessed through (https://www.gpo.gov/fdsys/granule/STATUTE-100/STATUTE-100-Pg2085/content-detail.html).
[11] The Energy Policy Act of 1992 can be accessed through (https://www.gpo.gov/fdsys/pkg/STATUTE-106/pdf/STATUTE-106-Pg2776.pdf).
[12] The Energy Policy Act of 2005 can be accessed through (https://www.gpo.gov/fdsys/pkg/PLAW-109publ58/content-detail.html).

With the passage of the 2005 Act, the original Business Investment Tax Credit had evolved from covering multiple sectors to just focusing on energy and primarily solar, geothermal, and other forms of renewable energy. The Act also increased the tax credit for eligible installations to 30 percent. Starting January 1, 2006, utility and commercial-scale solar installers could now receive a 30 percent credit (under IRC section 48) on installations placed in service during the taxable year as well as residential installers (under IRC section 25D).

Because of the significant changes to the ITC under the 2005 Energy Policy Act, one of the largest trade associations for the solar industry, the Solar Energy Industries Association (SEIA), described the Act as "creating" the "Solar Investment Tax Credit" and stated the credit was "*one of the most important federal policy mechanisms to support the deployment of solar energy in the United States.*"[13] Furthermore, the text of the Act itself officially re-branded the ITC the "Business Solar Investment Tax Credit."[14] Although, since the policy is now applicable to multiple RE sources it is more commonly referred to as the "Business Energy Investment Tax Credit" or simply, the ITC.

As mentioned, many claim the expansion of the ITC was critical to lowering the barriers to entry so that solar energy suppliers and installers could compete with traditional fossil fuel industries. Indeed, there has been an observed growth boom in U.S. solar over the past twenty years (both before and after the 2005 expansion – but more pronounced after, as my research shows). For example, one 2016 report prepared for the Office of Energy Policy and Systems Analysis at the U.S. Department of Energy estimated that installed capacity of PV systems grew 60% per year throughout the 2000s and 70% per year so far in the current decade. The report

[13] Overview of the ITC by Solar Energy Industries Association can be accessed through (https://www.seia.org/initiatives/solar-investment-tax-credit-itc).
[14] The Energy Policy Act of 2005 can be accessed through (https://www.gpo.gov/fdsys/pkg/PLAW-109publ58/content-detail.html). See: Section 1337.

authors were so certain of the ITC's impact on solar growth they concluded, "*the deployment of solar PV has always been and continues to be dependent on public policy*" (Hart and Birson 2016).

Another report from the U.S. Energy Information Agency shows that wind and solar grew from less than one percent of total U.S. electricity supply just a decade ago to 7 percent in 2017.[15] Similarly, SEIA claims the "*ITC has helped annual solar installation grow [in the U.S.] by over 1,600 percent - a compound annual growth rate of 76 percent*."[16]

Despite these positive correlations, congressional re-authorizations of the ITC since 2005 have been disjointed. The 2005 Energy Policy Act originally funded the 30 percent tax credit only through the end of 2007. In other words, just one year of the policy's implementation from the Jan 1, 2006 start date. An extension was then passed in 2006 so that that ITC could continue one more year through the end of 2008. After the 2008 financial collapse, the ITC was extended for a longer period to provided market certainty to the domestic solar industry which had started to take off and create jobs. The policy was then allowed to expire at the end of 2014. The ITC was only narrowly renewed under the Consolidated Appropriations Act (P.L. 114-113) which was signed into law at the end of 2015; nearly a year after the ITC had expired. Due to the short-term expiration of the credit, the appropriations bill had to include a retroactive extension back to January 1, 2015 in order to provide credits to installers that had continued to install throughout that year.[17] The Act also included a "phase down" of the ITC which called for a reduction of the 30 percent credit for utility, industrial, commercial, and residential systems to 26 percent by 2020, 22 percent by 2021, and, starting in 2022, permanently just 10 percent just for utility, industrial, and commercial

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[15] *TIME* analysis of renewable energy growth and the impact of the 2017 tax reform bill can be accessed through (http://time.com/5042881/tax-reform-bill-solar-wind-power-renewable-energy/).
[16] Overview of the ITC by Solar Energy Industries Association can be accessed through (https://www.seia.org/initiatives/solar-investment-tax-credit-itc).
[17] The Consolidated Appropriations Act, 2016 can be accessed through (https://www.gpo.gov/fdsys/pkg/PLAW-114publ113/html/PLAW-114publ113.htm).

installations moving forward with no federal credit remaining for residential systems.[18] Finally, in 2017, initial iterations of the tax reform package that was eventually signed into law by President Trump (P.L. 115-97) contained language that would once again eliminate the ITC completely. The language eliminating the ITC was removed from the final tax bill before it was passed but the phase down is still current policy.

The instability in the ITC has largely been due to politics. But these political arguments have had a real effect on the history (and future) of the ITC. Some legislators feel the program has picked "winners and losers" in the domestic energy production market, led to job loss (in one sector), and led to a sectoral shift away from abundant and domestic sources of traditional fossil fuels that have provided reliable and affordable energy for generations. To some extent, the analyses in this paper support these claims. On the other side, some legislators tout the many benefits of the ITC. The full explanation of energy market shifts over recent decades is more complicated and includes many other important factors. This paper expands upon a few of those factors to provide a comprehensive analysis of the ITC.

III. LITERATURE REVIEW

Many studies have evaluated the impact of different types of federal energy tax incentives on traditional fossil fuels and some renewable energy sources.[19][20][21][22] However, comprehensive

[18] ITC analysis conducted by *Energy Sage* can be accessed through (https://www.energysage.com/solar/cost-benefit/solar-investment-tax-credit/)
[19] Comello, Stephen, and Stefan Reichelstein. "The U.S. investment tax credit for solar energy: Alternatives to the anticipated 2017 step-Down." Renewable and Sustainable Energy Reviews, vol. 55, 2016, pp. 591–602.
[20] Mai, Cole, et al. "Impacts of Federal Tax Credit Extensions on Renewable Deployment and Power Sector Emissions." National Renewable Energy Laboratory. 2016.
[21] Hymel, Mona. "The United States' Experience with Energy-Based Tax Incentives: The Evidence Supporting Tax Incentives for Renewable Energy." Law Journal Library. Loyola University Chicao Law Journal Vol. 38. 2006.

[22] Reichelstein, Stefan, and Michael Yorston. "The Prospects for Cost Competitive Solar PV Power." SSRN Electronic Journal, 2012, doi:10.2139/ssrn.2182828.

research on the effect of the ITC on the U.S. solar industry is sparse. The main challenge is the availability of nation-wide data on total solar installations per year. The Lawrence Berkeley National Laboratory has been compiling these data for a decade and has information on over one-million solar PV installations in a publicly available database. However, the data is voluntarily self-reported from a combination of various government entities, industry sources, and the public and there is a lot missing.

Since the ITC's increase to 30 percent just occurred in 2005, most previous ITC research has only been able to take a few years into consideration at the time of analysis. One "snapshot" of analysis – for instance, 2005-2007 – might result in very different findings regarding the ITC's impact respective to another snapshot – for instance, 2008-2012 – given differing macro-economic and political environments during these two periods. In order to provide more comprehensive analysis, this paper will build upon these snapshot ITC studies as well as other research that provide useful comparison indicators. To this latter regard, this paper will highlight key studies that have analyzed the effect of federal energy tax credits on the energy sector in general as well as studies that have analyzed the effect of the 1992 "Production Tax Credit" or "PTC" – a similar tax credit as the ITC but for the wind industry.

A study conducted in 2006 by Hymel discusses the beneficial effects of federal tax incentives on both traditional and alternative/RE sources since the early 1900's. She shows how carefully-crafted incentives can be vital to energy development as they help to reduce market barriers to entry. For instance, deductions and subsidies reduced marginal tax rates and production costs in the oil and gas industries. This helped companies reduce costs and increase exploration which led to the share of oil and gas in U.S. energy production increasing from 16 percent in 1920 to 71.1 percent in 1970.[23] In considering development of future RE incentives, Hymel suggests a lot can be learned from the effective implementation of oil and gas incentives. She also points to the PTC as an example of a successful program that reduced barriers to entry and helped accelerate installed wind electricity generating capacity in the United States (Hymel 2006).

The effect of the PTC is captured in greater detail by Wiser, Bolinger, and Barbose who claim the credit has been "*among the most significant drivers*" of the growth of the wind industry over the last decade (Wiser et al., 2007). Their study charts annual added capacity of wind installations from 1992-2006. Their findings show that in years where there were "lapses" in policy, due to last-minute extensions and/or short-term expirations of the credit, installations were dramatically lower than in years when the credit was fully available. This indicates a strong correlation between the availability of the PTC and annual wind energy installations (Wiser et al., 2007).

The Department of Energy's National Renewable Energy Laboratory (NREL) has conducted similar research. One 2016 study concluded that federal RE tax incentives and credits (such as the PTC for wind and ITC for solar) have been one of the primary drivers of accelerated RE installed capacity in the United States over the last two decades. The study also models future RE capacity scenarios based on continued availability of the ITC & PTC credits. Through 2030, there is a steady yearly increase in RE installed capacity both in the model that represents an extension of the credits as well as the model that represents the policies' expiration. However, RE capacity is significantly accelerated when credits are available.

The NREL study provides two additional conclusions relevant to this paper. First, future RE capacity (with or without tax credits) depends upon the price of natural gas. For the credit and

[23]History of energy tax policy prepared by the Congressional Research Service can be accessed through (https://fas.org/sgp/crs/misc/RL33578.pdf).

no-credit scenarios, the study includes two RE deployment tracts; one under base and one under low natural gas price assumptions. This modeling shows a high correlation between RE installed capacity and the price of natural gas. I will therefore need to include natural gas price in my analysis to account for this correlation. Secondly, the study creates a striking channel that starts from RE tax credits, moves through increased RE installed capacity due to the availability of the credits, and continues into impacts on cumulative carbon dioxide emissions in the electricity sector. The study finds that increased deployment of RE capacity due to RE credits results in an additional 540 million metric tons lower cumulative electric sector CO2 emissions from 2016–2030, compared to the scenario without RE credits, under the base natural gas price assumption (Mai et al. 2016).

The three previous studies highlight a few of many literary examples that show strong, positive connections between federal energy tax incentives and level of installed energy capacity. Yet, as discussed, there are different types of incentives and each energy source presents its own unique installation challenges. Additionally, many studies tend to combine different RE sources (and incentives) together in analysis; for instance, combining the ITC and PTC. This is done to provide useful comparisons between alternative/RE sources (as a bloc) and traditional fossil fuel sources (as a bloc). This paper, however, will need to separate out just the ITC from other RE incentives and just the solar PV industry from other RE sources to focus analysis.

What, then, constitutes a "substantial enough" incentive to reduce the barriers to entry for, and significantly impact growth in, just the solar PV industry? Is the ITC an example of that type of incentive? Research conducted by Reichelstein and Yorston addresses this question by providing economic models of cost competitiveness – known as the Levelized Cost Of Energy (LCOE) -- for commercial and utility-scale solar PV. They conclude that (as of 2011), while utility-scale PV installations were not cost competitive with fossil fuel power plants, commercial-scale installations had attained cost parity in some parts of the U.S. – at least in terms of retail electricity prices. The cost parity achieved in one sub-sector of the solar PV industry was also shown by Reichelstein and Yorston to crucially depend upon federal tax subsidies like the ITC. They modeled the 30 percent ITC into their LCOE estimates and showed significant price differences in both commercial and utility-scale solar PV when the credit was removed. Location was another important factor and, as such, will need to be included in my analysis (Reichelstein and Yorston, 2012).

If increasing the ITC to 30 percent more than a decade ago did meet the cost-reduction threshold to reduce barriers to entry, which led to the significant observed industry growth since, then what analysis has already been done to quantify the policy's effect? From my literature review, it seems that Bloomberg New Energy Finance (BNEF) has produced the most in-depth studies so far. Claims made of the ITC's positive impact by Solar Energy Industries Association (SEIA), mentioned earlier, are based on BNEF analysis. While BNEF data is mostly subscription-based, their data visualization from an August 2014 study is publicly-available as a factsheet on the BNEF website.

The BNEF report/factsheet uses bar graphs that track installed solar PV capacity from 2011-2014 and project installed capacity from 2015-2021. Since the 2015 re-authorization of the ITC was uncertain at the time of the report, it included two scenarios for the 2015-2021 timeline: assuming no extension of tax credits and assuming a five-year phase out of tax credit. According to BNEF, no extension of the 30 percent ITC would have resulted in cumulative 2016-2021 installed solar PV capacity of 41GW. In the extension scenario, the cumulative installed capacity is 59GW; or 144% higher than the no-extension scenario.[24]

To put the BNEF findings another way, Calvert Cliffs Nuclear Power Plant in Maryland has two reactors that produce 2GW of energy total which is enough to power more than one million homes.[25] The 18GW difference over five years between the scenario in which the ITC was eliminated and the scenario in which it was extended was therefore equivalent to the impact of nine double-reactor nuclear power plants being built over five years – which is enough generating capacity to power nine million homes.

The BNEF study also did not project the impact of the ITC's full continuation at 30 percent but rather the impact of the phase down. As noted, installed solar PV capacity is still much higher in this scenario than the no-extension scenario. For instance, even at an ITC of 22 percent in 2021, BNEF project 10.8GW of installed solar capacity that year (a 3.4GW increase over the no-extension scenario). If policy changes are made in coming years that allow the ITC to remain at 30 percent through 2021 (or later) it is plausible that installed solar capacity could be much higher than 59GW during this five-year period.

IV. CONCEPTUAL FRAMEWORK

The conceptual framework for this paper is modeled on the hypothesis that the 30 percent ITC positively impacted yearly installed solar PV capacity in the United States from 2006-2015 and that this effect was higher than the years in my analysis when the credit was only 10 percent (1997-2005). As mentioned in the introduction, it is likely that there would be an observed positive

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[24] Information on the impact of tax credit extensions on wind and solar prepared by Bloomberg New Energy Finance can be accessed through (https://about.bnef.com/blog/impact-of-tax-credit-extensions-for-wind-and-solar/).
[25] Information on the Calvert Cliffs Nuclear Power Plant can be accessed through (http://www.exeloncorp.com/locations/power-plants/calvert-cliffs).

effect on installed solar PV capacity due to the increase of the credit due to the nature of the policy – a dollar-for-dollar reduction in the income taxes that a person or company claiming the credit would otherwise pay the federal government. If this increase successfully reduced the barrier to entry for competition in the energy sector, we might expect more solar PV installers to enter the market. This, in turn, might create an increase in installed, yearly solar PV capacity.

To test this hypothesis, this paper mainly examines whether there are observed trends in higher levels of installed solar PV (in KW) in the years when the ITC was increased to 30 percent compared to previous years. Additional indicators of growth in the solar industry are also used to test the robustness of outcomes from different measures. If a significant relationship is found, this may help back up stakeholder claims and guide future policy decisions regarding the ITC.

4.1 Empirical Model

The methodological framework of this paper is built upon state/year fixed-effects panel data analysis using the baseline model:

$$Y_{i,t} = \beta_0 + \beta_1 X_{i,t} + \sum_{n=1}^{N} Z_{i,t} + \gamma + \lambda + \varepsilon_{i,t}$$

where, $Y_{i,t}$ is the dependent variable of interest (state/year sum of added solar PV in KW), $X_{i,t}$is a variable coded to represent the 30 percent ITC and $\sum_{n=1}^{N} Z_{i,t}$is a vector of control variables accounting for important confounding factors (such as GDP, unemployment, etc.). The factor γ accounts for state fixed effects, λ for time fixed effects, and $\varepsilon_{i,t}$is the error term. I use state fixed effects to control for similar characteristics that all U.S. states would have observed during my time span of analysis. I include time fixed effects to account for temporary shocks that occur across all states in a given year (e.g., the Great Recession of 2008).

4.2 Data Description

My study was conducted using solar PV installation data provided by the Lawrence Berkeley National Laboratory and National Renewable Energy Laboratory's "Open PV Project" database (both part of the United States Department of Energy); state-level estimates of energy production, consumption, prices, and expenditures by all sources and sectors energy data provided by the U.S. Energy Information Agency (also part of DOE); annual GDP by state, in Current Dollars, for all industries provided by the North American Industry Classification System, Bureau of Economic Analysis (U.S. Department of Commerce); state-level unemployment rates provided by the Bureau of Labor Statistics (U.S. Department of Labor). The dataset includes all 50 states and the District of Colombia.

The key dependent variable of interest – state/annualized added capacity of installed, grid-connected, residential and non-residential solar PV (in KW) in the United States – comes from the Open PV Project database. I downloaded their entire database of over 1 million observations from 1969-2017. For my analysis, I have collapsed these data into 15 key variables and narrowed the years from 1997-2015. I chose to look at state-annual level data of solar PV from 1997-2015 because this time span includes roughly 10 years of data prior to the implementation of the ITC and roughly 10 years after, ending with the most recent year of data available.

The key independent variable of interest is a dummy variable that corresponds with the 30 percent ITC policy's implementation. I coded the variable as 1 for the years in my analysis during which the 30 percent ITC was available (2006-2015) and coded as 0 for the years prior (1997-2005) when the ITC was only 10 percent. The dummy variable is applied to all states as a block treatment.

Additional variables of interest were taken from the U.S. Energy Information Agency's state-level estimates of energy production, consumption, prices, and expenditures by all sources and sectors. These variables include other cost, price, and consumption factors for the solar PV industry, the price of consumption levels coal, and price and consumption factors for natural gas.

In controlling for the impact of carbon dioxide emissions reductions on my main dependent variable as well as looking at the impact of the ITC on carbon dioxide emissions (separate from my main thesis but important for policy implications) I take variables from the U.S. Energy Information Administration's state energy data system data.

Other relevant variables from these data and other data sets I used can be viewed in my codebook.

V. RESULTS

Table 1 describes different specifications for my baseline model of the effect of the ITC on installed solar capacity (KW). Model 1 starts with a simple OLS regression with no state or year fixed effects. Model 2 adds state fixed effects. Model 3 adds time fixed effects. Model 4 introduces a GDP control variable. Model 5 adds an unemployment control variable. In this Table and all future Tables, installed solar capacity is logged, GDP is logged, and unemployment is not logged (since it is already in percentage). Additional controls introduced in future tables are all logged as well.

In my final model with state and year fixed effects and two control variables added, the coefficient for the ITC variable is positive and highly significant. Model 5 shows a 352 percent increase in installed solar capacity due to the effect of the 30 percent tax credit compared to years when the tax credit was 10 percent. Adding fixed effects and simple controls does not impact the significance of my model which is statistically significant at the 1% level.

Table 1. Baseline OLS and Fixed Effects Regressions.

	(1) OLS	(2) FE	(3) FE	(4) FE	(5) FE
30% Tax Credit	3.121***	3.775***	3.315***	3.639***	3.523***
	(0.226)	(0.243)	(0.359)	(0.413)	(0.439)
GDP				-3.081	-2.156
				(2.006)	(2.079)
Unemployment					0.130
					(0.112)
Constant	3.658***	3.206***	4.085***	41.61*	29.70
	(0.166)	(0.168)	(0.214)	(24.42)	(25.46)
State FE	-	Yes	Yes	Yes	Yes
Year FE	-	-	Yes	Yes	Yes
Observations	635	635	635	635	635
R-squared	0.192	0.441	0.658	0.660	0.662
F-statistic	191.0	242.0	33.46	33.61	35.96
Number of States		51	51	51	51

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Note: author's own calculations.

Despite the positive initial results, there are clearly many omitted factors that could also have contributed to the increase of installed solar PV capacity during the years correlated with the 30 percent tax credit. These omitted variables could account for some of the high (and likely inflated) effect of the ITC on solar PV in my baseline. In further models for instance, I take into consideration costs associated with installing solar PV systems over time. It is theoretical that as solar technology improved over the 2006-2015 time period, which in turn had an effect on reducing the cost of building solar PV systems and increasing the efficiency of output, the number of installations would have increased regardless of the ITC's increase to 30%. Additionally, to what extent is the price of solar over time a function of the tax credit? To answer this question, including additional controls that enable the model to reflect increases or decreases in price due to the tax credit is useful.

Table 2, Model 1 starts with my preferred baseline from Table 1 (Model 5) for initial comparison. Models 2-3 control for the impact that price of other dominant sources of electricity may have on installed solar capacity. Model 2 adds the price of natural gas in the electric power sector (in dollars per million Btu, logged) which I identified previously in this paper as a necessary control in my analysis. Results show that there is a negative association between natural gas price and installed solar PV capacity due to the 30 percent ITC however this result is not statistically significant. Model 3 adds coal price in the electric power sector (in dollars per million Btu, logged). The results show that as the price of coal increases, installed solar capacity increases and this result is statistically significant. Model 4 adds both energy price comparison controls which continues to reduce the coefficient on the 30 percent tax variable. However, there could be collinearity concerns when including both controls as the price of coal might also be related to the price of natural gas, while also being related to installed solar PV capacity.

Model 5 removes both energy price comparison controls and includes the average cost per watt of total annualized installed solar PV capacity. Controlling for the cost of solar PV could help to explain some of the effect of the ITC on installed solar capacity. As referenced in my baseline model analysis, it is theoretical that as technological improvements in solar PV are made over time, installations may become more productive and efficient and therefore could impact the cost per watt of solar PV generated. What the results of Model 5 find, however, is that addition of this control, while negatively associated with installed solar capacity – which makes sense, as the average cost per watt falls, installations might theoretically increase – produces results that are not statistically significant.

Model 6 adds another price control within the solar PV industry, average cost of an individual solar PV installation. I generated this variable in my analysis by dividing the total number of installations in a state in a given year by the sum of the cost of all the installations in that state that year. Addition of this control is statistically significant and produces a large positive effect which indicates that as installed solar capacity increases, so does the average installation cost. This effect could be explained if more larger utility and industrial-scale installers are taking advantage of the ITC (and thus installing more costly systems) than smaller residential and commercial-scale installers. This is, in fact, what studies such as the 2014 BNEF analysis show.[26]

Model 7 adds all energy price controls back in which reduces the coefficient on the ITC variable but not below my baseline model. This could indicate that controlling for the prices of other energy sources like natural gas and coal help to explain more of the variation in the ITC variable coefficient than controlling for price and cost factors within the solar PV industry.

In Model 8, the average installation cost control is removed while the average cost per watt is left in, natural gas and coal prices are left in, and the sum of the cost of all solar PV installations made in that state that year is added. This produces some interesting results. First, the coefficient on the ITC variable reduces dramatically while remaining highly significant. The variable representing the sum of the cost of all solar PV installations is also significant at the one percent level. *Note: <u>all</u> control variables introduced in Table 2 and subsequent tables are in log form.

Additional analysis can be done to explain the effects of these controls in more detail. Broadly, my results show that, despite the introduction of various price and cost controls, the conclusions from my baseline model do not change. The impact of the 30 percent credit's effect on installed solar capacity remains strikingly robust.

[26] Information on the impact of tax credit extensions on wind and solar prepared by Bloomberg New Energy Finance can be accessed through (https://about.bnef.com/blog/impact-of-tax-credit-extensions-for-wind-and-solar/).

Table 2. Fixed Effects Regressions Adding More Controls.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	FE	FE	FE	FE	FE	FE	FE	FE
30% Tax Credit	3.523***	3.452***	3.254***	3.164***	3.408***	3.444***	3.486***	1.623***
	(0.439)	(0.661)	(0.484)	(0.702)	(0.515)	(0.533)	(0.793)	(0.523)
GDP	-2.156	-2.153	-1.899	-1.895	-1.030	-1.111	-0.777	-0.105
	(2.079)	(2.076)	(2.068)	(2.063)	(1.975)	(2.013)	(1.997)	(1.651)
Unemployment	0.130	0.131	0.132	0.134	0.113	0.109	0.0961	0.190*
	(0.112)	(0.114)	(0.109)	(0.111)	(0.109)	(0.118)	(0.113)	(0.0999)
Nat Gas Price		-0.0923		-0.115			0.409	-0.0260
		(0.558)		(0.557)			(0.666)	(0.465)
Coal Price			1.050	1.055			1.168	0.687
			(0.972)	(0.976)			(1.042)	(0.687)
Average Solar PV CPW					-0.0821	-0.0284	-0.0271	-0.281
					(0.420)	(0.440)	(0.436)	(0.458)
Average Solar PV Installation Cost						2.953	3.449	
						(2.852)	(2.621)	
Sum of All Solar PV Install Cost								0.493***
								(0.0792)
Constant	29.70	29.87	25.66	25.84	16.49	17.44	11.38	-1.542
	(25.46)	(25.56)	(25.38)	(25.45)	(24.51)	(25.03)	(24.95)	(20.91)
Observations	635	635	635	635	539	530	530	539
R-squared	0.662	0.662	0.663	0.663	0.680	0.680	0.682	0.812
Number of States	51	51	51	51	51	51	51	51

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: author's own calculations.

There could still be many other factors impacting the increase of solar PV capacity from 2006-2015 that I have not taken into consideration. One such factor, clear in the distribution of observations in my data, is the skew key states like California might be having on my results.

There are six key states I observed in my data that have much higher solar PV installation counts relative to the average installation count observed in other states. These states may enjoy locations more conducive to solar energy than other states (IE: more days of sunshine) and, aside from the benefits they may have experienced from the ITC federal policy, they have all also passed state and local policies to incentivize solar PV installation.

In Table 3, I begin to address the problem of skew in my results. Model 1 removes California with my baseline controls as California has the highest observed count of solar installations in my data by a large percentage. Model 2 removes California, Arizona, Massachusetts, New York, New Mexico, and Nevada. Models 3-4 add the two controls from Table 2 that reduced the coefficient on the ITC variable most significantly – price of coal and the sum of the cost of all solar PV installations. Models 4-5 add average solar PV cost per watt and price of natural gas back in.

In this sub-group regression, addition of all of the controls from Table 2 (except for average solar PV installation cost; opting instead to use sum of install cost since it was a better indicator to explain the variation in the ITC variable in Table 2) reduces the coefficient on the ITC variable to its lowest point yet. Accounting for these controls along with location seems to explain the effect of the 30 percent credit on installed solar capacity more than two-fold over my baseline model. Clearly, my baseline was experiencing a skewed effect from states with large observation counts as well as omitted variable bias from price and cost factors. Nevertheless, my subgroup-regression models also show that even by removing the states that may have benefitted the most from location and/or supportive state or local policies (compared to the average state/year observation count) the tax credit is still highly significant and positively correlated with installed solar PV capacity in all other states.

Table 3. Subgroup-regression Removing High Observation Count States.

	(1) FE	(2) FE	(3) FE	(4) FE	(5) FE	(6) FE
30% Tax Credit	3.556***	3.418***	3.145***	2.821***	1.483**	1.360**
	(0.445)	(0.492)	(0.578)	(0.636)	(0.570)	(0.572)
GDP	-2.472	-2.774	-2.682	-2.412	-0.596	-0.585
	(2.129)	(2.291)	(2.290)	(2.336)	(1.810)	(1.799)
Unemployment	0.158	0.158	0.159	0.157	0.237*	0.241*
	(0.114)	(0.134)	(0.130)	(0.134)	(0.129)	(0.127)
Coal Price			0.976	1.274	1.258	1.266
			(1.073)	(1.136)	(0.908)	(0.908)
Sum of All Solar PV Install Cost				0.0983***	0.449***	0.450***
				(0.0189)	(0.0809)	(0.0812)
Average Solar PV CPW					-0.440	-0.439
					(0.479)	(0.482)
Nat Gas Price						-0.147
						(0.465)
Constant	33.02	35.99	34.07	29.76	4.099	4.261
	(25.97)	(27.84)	(27.92)	(28.52)	(22.25)	(22.30)
Observations	616	536	536	536	444	444
R-squared	0.657	0.630	0.631	0.654	0.783	0.783
Number of States	50	45	45	45	45	45

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Note: author's own calculations.

In Table 4, I continue to try to model the effect of supportive state and local policies from a different vantage point. I return to my baseline model in Model 1 and, in Model 2, add state energy-related carbon dioxide emissions by year (2000-2014, in million metric tons of carbon dioxide). It is possible that the 30 percent ITC would *also* have had an effect on a state's energy-related CO2 emissions. However, I have included this variable on the right-hand side of my analysis for now, relative to installed solar PV capacity, for a couple of reasons.

First, state and/or local policies to incentivize renewable energy development would inherently have an effect on solar PV capacity. Currently, there are 29 states that have "State Renewable Portfolio Standards and Goals" that require utilities to sell a specified percentage or amount of renewable electricity.[27] In Nevada, for instance, a 1997 state standard established that 25 percent of the state's energy should come from renewable energy sources by 2025. Furthermore, the standard details that solar should account for 5 percent of annual requirement through 2015 and 6 percent for 2016-2025. Nevada passed a state policy incentive separate from the ITC to help meet these goals.[28]

Secondly, if state and local policies are helping to increase the share of renewable energy sources in their energy mix then there might also be an observed reduction in energy-related carbon dioxide emissions in that state due to these policies. Some states even have specific policies that set state-wide carbon emissions reductions goals and list solar PV as one potential mechanism for achieving their targets. California, for instance, passed AB32 (AKA: the "Global Warming Solutions Act of 2006") which, along with Executive Order S-3-05, requires the state to reduce its greenhouse gas emissions levels 80% below 1990 levels by 2050.

It would be very difficult to control for all state and local policies passed to meet the renewable portfolio standards and various emissions reductions goals. However, since most (if not all) of these policies would increase solar PV (and other RE sources) capacity and thereby reduce CO2 emissions in the state it might be possible to account for the missing effect of these policies in my analysis by controlling for the latter.

[27] Information on the state renewable portfolio standards and goals can be accessed through (http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx).
[28] Nev. Rev. Stat. §704.7801 et seq.

In Model 3, I add just energy intensity by state (2000-2014, in thousand Btu per chained 2009 dollar of GDP) to my baseline. It's possible that over the years, as GDP grew, so did energy intensity by state. As the demand for energy increased over time, deployment of all forms of energy (including solar) to meet this demand might be observed. By controlling for GDP and this new variable, I attempt to account for this effect.

In Model 4, I add both state-energy related CO2 emissions and energy intensity by state to ensure my models are clearly observing all fluctuations on the coefficient of my tax credit variable.

In Model 5, I add total energy consumption. This is one more control to account for the growth of energy demand per state over time that may have contributed to increased deployment of all forms of energy including solar PV.

In Model 6, I add back in most of my energy price and cost controls from previous Tables. In Models 7-8, I remove the high observation count states from Table 3 to control for any lingering effect from state and local policies using all methods in my analysis that I have set up to attempt to control for this effect.

While some observations are lost – since the time period for analysis with these controls is only 2000-2014 – the models in Table 4 produce notable results. Primarily, my results indicate that when controlling for state and local policies that may have reduced CO2 emissions and energy intensity (and therefore may have incentivized solar PV deployment in parallel to the ITC) the effect of the ITC on installed solar PV capacity is still highly significant and positively correlated. Secondly, the controls for state CO2 emissions and energy intensity are statistically significant. This result could support my secondary hypothesis that there have been observed benefits in CO2 reduction due to the 30 percent ITC policy. I will test this hypothesis more robustly in Table 8.

Table 4. Modeling the Impact of CO2 Reductions and Energy Intensity, Potentially due to State and/or Local Policies.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	FE	FE	FE	FE	FE	FE	FE	FE
30% Tax Credit	3.523***	3.349***	3.892***	3.246***	3.257***	1.362**	3.296***	1.388*
	(0.439)	(0.579)	(0.526)	(0.594)	(0.590)	(0.635)	(0.633)	(0.703)
GDP	-2.156	-4.053	-5.779**	-1.975	-3.036	1.043	-2.411	0.645
	(2.079)	(2.562)	(2.804)	(2.554)	(2.567)	(2.667)	(2.747)	(2.779)
Unemployment	0.130	-0.0117	0.0149	-0.00491	0.000477	0.0738	0.0316	0.134
	(0.112)	(0.118)	(0.123)	(0.117)	(0.115)	(0.105)	(0.143)	(0.140)
State Energy-related CO2 Emissions		-4.065**		-5.712***	-7.285***	-4.802**	-5.082**	-5.045**
		(1.861)		(2.078)	(2.511)	(1.877)	(2.107)	(2.072)
State Energy Intensity			-1.140	3.091**	3.011**	1.676	3.250**	1.786
			(1.840)	(1.424)	(1.423)	(1.609)	(1.496)	(1.621)
Total Energy Consumption					3.490			
					(3.134)			
Coal Price						1.099		1.145
						(0.872)		(1.024)
Natural Gas Price						0.0979		0.0371
						(0.409)		(0.403)
Average Solar PV CPW						-0.318		-0.432
						(0.503)		(0.541)
Sum of All Solar PV Install Cost						0.448***		0.410***
						(0.0794)		(0.0768)
Constant	29.70	71.15**	76.51**	46.58	17.29	2.991	47.07	8.497
	(25.46)	(31.09)	(35.84)	(30.64)	(45.71)	(31.31)	(32.83)	(32.59)
Observations	635	552	552	552	552	474	470	393
R-squared	0.662	0.653	0.647	0.655	0.656	0.797	0.619	0.760
Number of States	51	51	51	51	51	51	45	45

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Note: author's own calculations.

Accounting for location, state and local policies, and various energy sector price and cost controls may help to explain much of the effect of the 30 percent ITC on installed solar PV capacity. However, there are additional ways in which to evaluate "growth" in the solar industry due to the ITC. In Table 5, I run my preferred baseline model specification (Table 1, Model 5) with different dependent variables in order to view the effect of the tax credit policy on different growth outcome measures. Models 1 and 2 show the OLS and FE regression results for what has so far been the dependent variable for all my previous models; total annualized installed solar PV capacity (in KW). Models 3 and 4 show OLS and FE regression results using the number of solar PV installations in a state in a given year. Models 5 and 6 show OLS and FE regression results using the sum of total estimated annual PV generation (in KW). Models 7 and 8 show OLS and FE regression results using the total solar energy consumed for electricity generation by the electric power sector. Models 9 and 10 show OLS and FE regression results for total solar energy consumed across all sectors

In all models, the tax credit remains positive and highly significant. These results support my primary hypothesis that the ITC has had a positive and significant effect on installed solar PV capacity no matter which indicators of growth are used to measure the industry over time. Furthermore, my results show that not only production but also consumption is consistent and correlated with the ITC. This 1-1 pass through effect of the ITC on production and consumption is consistent with my primary hypothesis.

Table 5. Effect of Tax Credit on Different Outcome Measures.

Dependent Variable	Total Installed KW of Solar PV/yr		Total Solar Install Count/yr		Total Estimated annual PV Generation in KW/yr		Total Solar Energy Consumed for Electricity Generation by the Electric Power Sector		Total Solar Energy Consumed Across all Sectors	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	OLS	FE	OLS	FE	OLS	FE	OLS	FE	OLS	FE
30% Tax Credit	3.121***	3.523***	1.990***	2.481***	2.643***	4.003***	1.738***	3.773***	1.126***	2.204***
	(0.226)	(0.439)	(0.182)	(0.443)	(0.574)	(1.140)	(0.146)	(0.516)	(0.143)	(0.191)
GDP		-2.156		-3.023		-2.563		0.318		0.201
		(2.079)		(2.202)		(5.931)		(2.565)		(0.761)
Unemployment		0.130		-0.0376		-0.0963		0.396**		0.0491
		(0.112)		(0.101)		(0.346)		(0.167)		(0.0443)
Constant	3.658***	29.70	2.353***	39.66	5.040***	37.28	0.204***	-5.502	4.416***	1.801
	(0.166)	(25.46)	(0.132)	(26.96)	(0.434)	(72.95)	(0.0574)	(31.20)	(0.102)	(9.219)
Observations	635	635	635	635	635	635	969	969	969	969
R-squared	0.192	0.662	0.126	0.570	0.027	0.406	0.120	0.475	0.060	0.640
Number of States		51		51		51		51		51

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: author's own calculations.

Tables 1-5 support my primary hypothesis and help explain the impact of the ITC on installed solar PV capacity (as well as other indicators of growth in the solar PV industry) from a few different perspectives. In all models, the effect of the ITC remains robust and positively associated with installed solar PV capacity. Figure 1 shows a visual representation of this relationship for the entire timespan of my analysis (1997-2015). From 1997-2005, there is positive yearly solar PV growth. Starting around 2006, however, this yearly growth increases rapidly. Figure 1 also shows that, starting around 2013, the average yearly size of installations per state (in terms of KW) increased.

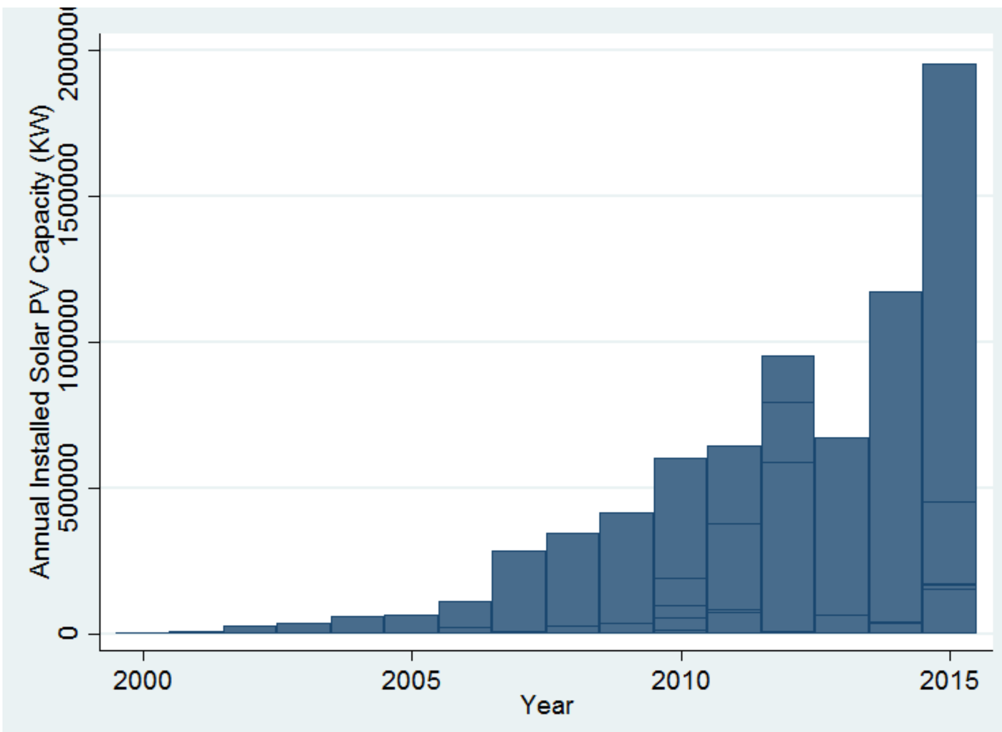

Figure 1. Annual Installed Solar PV Capacity (in KW) from 1997-2015.

One of the purposes of my research was to also evaluate my secondary hypothesis that there have been observed benefits in CO2 reduction due to the ITC. As mentioned in my introduction, if there an observed positive effect between the ITC and deployment of installed solar

PV capacity (which is a zero-carbon, renewable energy technology) can be observed then it's plausible there might be a positive relationship between the ITC and CO_2 emissions reductions. My research shows this positive effect between the ITC and solar PV. In order to show the effect between the ITC and CO_2 emissions, expand my model in a couple ways.

In Table 4, I included state energy-related CO_2 emissions from 2000-2014 on the right-hand side of my analysis to control for the effect supportive state and local policies may have had on installed solar PV capacity (since state and local policies to reduce CO_2 emissions might have led to a positive effect on solar PV). In Table 6, I move this control to the left-hand side to model what effect the ITC may have had directly on one indicator of CO_2 emissions reductions. For other indicators in Table 6, I use per capita energy-related CO_2 emissions by carbon intensity of the energy supply by state (both from 2000-2014).

In Model 1, I again start with my baseline for ease of comparison. In Models 2-7, I test two scenarios for each of my three different dependent variables representing different perspectives on CO_2 emissions. The first scenario (A) represents my baseline controls. The second scenario (B) adds total energy production to control for overall growth in energy supply over time as well as coal price to control for the impact that the price of the most dominant source of energy during this time period might have had on CO_2 emissions indicators.

Every model shows a very significant, negative relationship between the 30 percent ITC and indicators of state / year CO_2 emissions. This robust result supports my secondary hypothesis. It does appear that the increase of the ITC to 30 percent in 2005 helped drive emissions reductions across the energy sector and state-wide economy as a whole.

Table 6. Testing Secondary Hypothesis.

Dependent Variable	Total Installed KW of Solar PV/yr	State energy-related carbon dioxide emissions (2000-2014)		Per capita energy-related carbon dioxide emissions by State (2000-2014)		Carbon intensity of the energy supply by State (2000-2014)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Baseline	A	B	A	B	A	B
30% Tax Credit	3.523***	-0.130***	-0.122***	-0.164***	-0.159***	-0.0945***	- 0.101***
	(0.439)	(0.0211)	(0.0233)	(0.0230)	(0.0242)	(0.0156)	(0.0264)
GDP	-2.156	0.296***	0.222***	0.0315	-0.0425	-0.0398	-0.00904
	(2.079)	(0.0770)	(0.0786)	(0.119)	(0.106)	(0.0643)	(0.0641)
Unemployment	0.130	-0.0116*	-0.0115*	-0.0194**	-0.0193**	0.000241	0.000174
	(0.112)	(0.00628)	(0.00602)	(0.00843)	(0.00825)	(0.00452)	(0.00427)
Total Energy Production			0.0685***		0.0699***		-0.0267
			(0.0166)		(0.0209)		(0.0184)
Coal Price			-0.0699		-0.0622		0.0383
			(0.0483)		(0.0526)		(0.0471)
Constant	29.70	0.850	0.919	2.840*	2.883**	4.584***	4.525***
	(25.46)	(0.937)	(0.880)	(1.447)	(1.223)	(0.785)	(0.784)
Observations	635	765	765	765	765	765	765
R-squared	0.662	0.469	0.534	0.658	0.698	0.598	0.620
Number of States	51	51	51	51	51	51	51

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: author's own calculations.

In my final table, I go further in modeling additional secondary outcomes of the ITC. These outcomes correspond with some of the positive and negative arguments associated with the impact of the ITC that I've referenced throughout this paper.

In Table 7, I start with my baseline. In Models 2-3, I model the effect of the ITC on the average cost per watt (cost $/W) of a solar PV installation. Many claim that the 30 percent tax credit has not only helped to drive increased solar PV installations at a static price but that it has also helped drive down installation costs which, in turn, has helped grow the solar industry at an even faster rate. Indeed, the average cost $/W of solar PV in 1997 (at the start of my analysis) was $6.11, in 2005 (right before the 30 percent ITC went into effect) was $7.56, and today is $3.21.[29] Remember that research conducted by Reichelstein and Yorston showed that only in 2011 did commercial-scale solar PV installations attain cost parity with fossil fuel power plants (and only in some parts of the U.S). Meanwhile, at the time of their research, utility-scale PV installations were still not cost competitive with fossil fuel power plants. Across the entire solar PV industry, the ITC was shown to be a critical factor in reducing the levelized cost of energy.

Model 2 includes my baseline controls. Model 3 controls for the price of coal. My results indicate the ITC is significantly and negatively associated with the average cost $/W of solar PV. Figure 2 visualizes the falling cost $/W more comprehensively during the years in my analysis.

[29] Information on the "Open PV Project" from the National Renewable Energy Laboratory can be accessed through (https://openpv.nrel.gov/index).

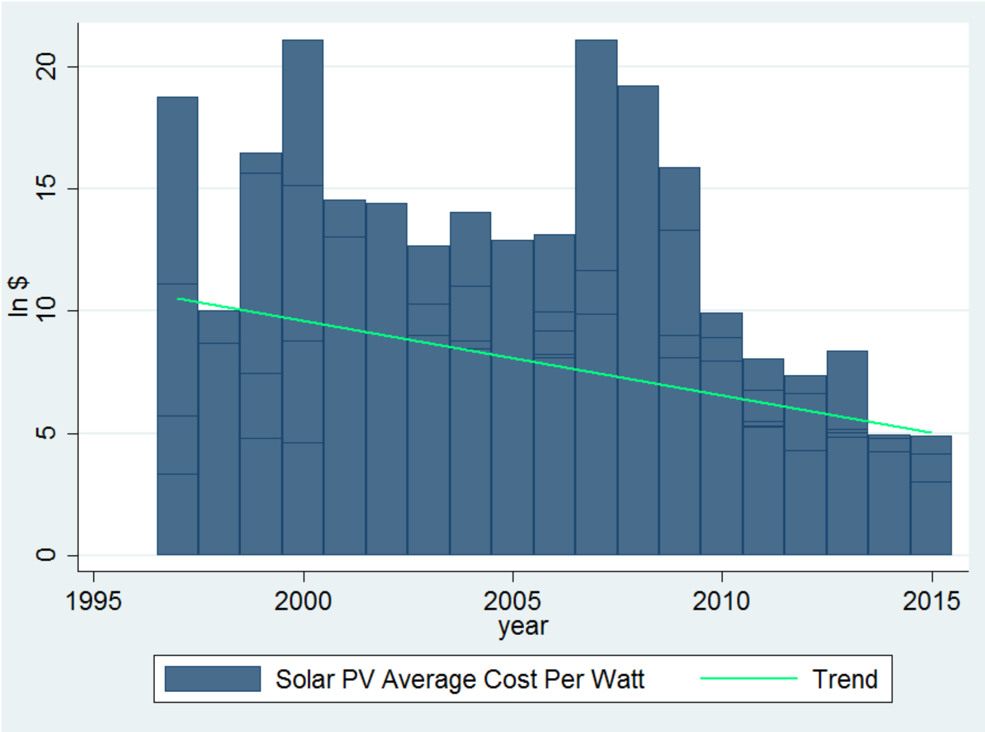

Figure 2. Falling Average Cost $/W of Solar PV Installation.

In Models 4-5, I show the relationship between the ITC and coal price in the electric power sector. Model 4 controls for my baseline and Model 5 controls for the price of natural gas. My results show a significant and positive effect between the tax credit and an increase in the price of coal in the electric power sector. This could indicate that, even when controlling for the falling price of natural gas (typically the largest economic indicator on the price of coal in recent decades), the ITC has still had an effect on coal prices.

In Models 6-7, I show the relationship between the ITC and coal consumed by the electric power sector. In Model 6 I control for my baseline and in Model 7 I control for natural gas consumed by the electric power sector. Again, despite controlling for the disruptive effect natural gas has been observed to have on the coal industry, the ITC is still shown to have a significant and negative effect on coal consumption for power.

Table 7. Testing Different Outcome Measures.

Dependent Variable	Total Installed KW of Solar PV/yr	Average Cost Per Watt of Solar		Coal price in the electric power sector		Coal consumed by the electric power sector	
	(1) Baseline	(2) A	(3) B	(4) A	(5) B	(6) A	(7) B
30% Tax Credit	3.523***	-0.605***	0.595***	0.272***	0.297***	-0.659***	0.655***
	(0.439)	(0.0655)	(0.0764)	(0.0288)	(0.0433)	(0.143)	(0.149)
GDP	-2.156	-0.308	-0.319	-0.141	-0.153	0.301	0.323
	(2.079)	(0.367)	(0.372)	(0.108)	(0.108)	(0.361)	(0.391)
Unemployment	0.130	0.000862	0.00101	0.00719	0.00685	-0.0276	-0.0266
	(0.112)	(0.0151)	(0.0150)	(0.00917)	(0.00919)	(0.0203)	(0.0210)
Coal Price			-0.0394				
			(0.125)				
Natural Gas Price					0.0313		
					(0.0342)		
Natural gas consumed by the electric power sector							-0.00852
							(0.0217)
Constant	29.70	6.018	6.186	2.525*	2.601**	5.174	4.990
	(25.46)	(4.552)	(4.628)	(1.305)	(1.294)	(4.369)	(4.625)
Observations	635	539	539	969	969	969	969
R-squared	0.662	0.588	0.588	0.763	0.763	0.250	0.250
Number of States	51	51	51	51	51	51	51

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Note: author's own calculations.

The policy implications of Table 7 are wide ranging and will be expanded upon in the next section. However, to visualize the rapidly changing relationship between solar PV, coal, and natural gas for power generation, I have included two additional figures below. Figure 3 shows the relationship between the decline of yearly coal consumption and the increases in yearly natural gas and solar consumption in the electric power sector (all in billion Btu). My results show that, since

2010, solar has grown dramatically in yearly consumption by the energy sector in relation to both natural gas and coal.

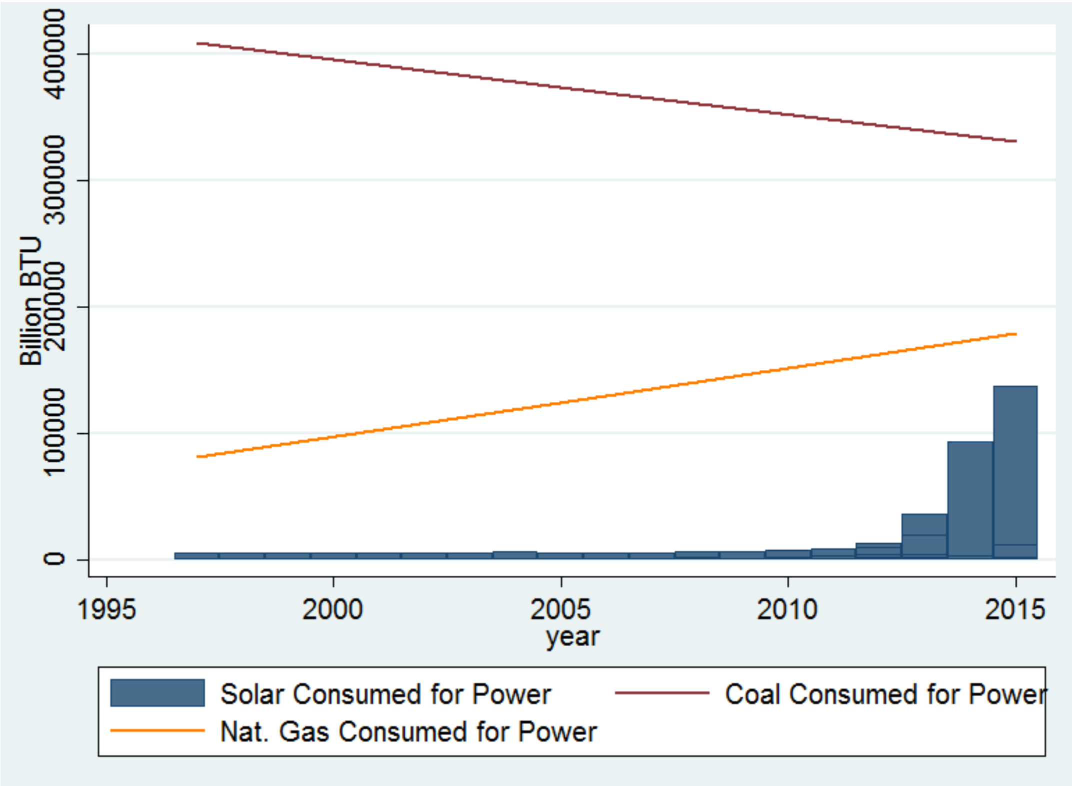

Figure 3. Consumption in the Electric Power Sector.

In Figure 4, the relationship is even more striking. By using the same indicators for natural gas and coal as Figure 3 but switching the solar indicator to total solar energy consumed across the entire economy (as opposed to just the energy sector) my model is able to include residential and other non-power sector forms of solar PV not accounted for in Figure 3. Since there are no residential coal or natural gas power plants, this is still a 1-1-1 comparison of these three energy sources. Figure 4 shows that by taking the whole solar industry into consideration, solar surpassed natural gas in 2015 for the first time in yearly capacity additions. This observation from my results is consistent with other research.[30]

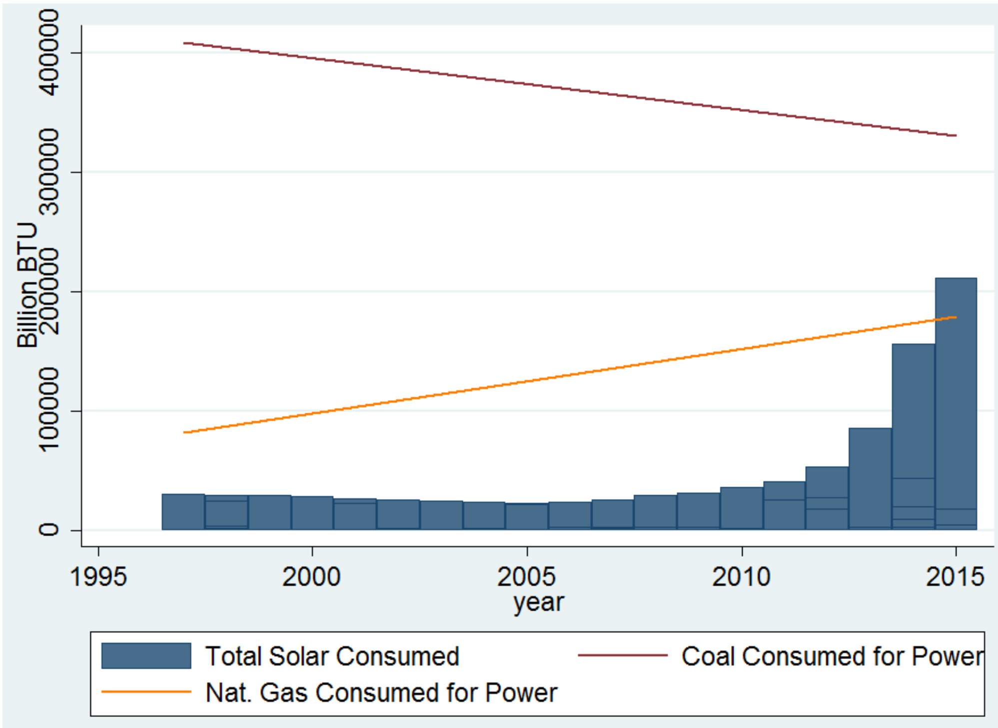

Figure 4. Total Solar Consumption vs. Coal and Natural Gas Power Consumption.

VI. SUMMARY OF FINDINGS, IMPLICATIONS, AND RECOMMENDATIONS

Give the many layers of analysis in this paper and statistical significance of my models, there are multiple findings of interest, policy implications, and recommendations. In this section, I discuss key findings related to both my primary and secondary hypotheses; potential future impacts of the ITC on both the solar industry and CO2 emission reductions; political and policy obstacles; and specific policy recommendations.

My research provides evidence to support both my primary hypothesis – that the 30 percent ITC has had a positive effect on installed solar PV capacity in KW/yr (as well as other

[30] Analysis of 2015 solar installations from Solar Energy Industries Association can be accessed through (https://www.seia.org/news/us-solar-market-sets-new-record-installing-73-gw-solar-pv-2015).

indicators of growth in the industry) – and my secondary hypothesis – that there have been observed benefits in CO_2 emissions reduction due to the ITC policy. As mentioned in my introduction, there are three main policy implications from these findings. Each of these will now be evaluated more thoroughly in separate sections.

6.1 Reduced Barriers to Entry

The first implication from my research is that the increase of the ITC from 10 percent to 30 percent successfully reduced the barriers to entry in the energy sector which enabled more firms to enter the market and provide higher levels of solar PV installations. This was achieved by the ITC's effect on reducing solar PV's Levelized Cost of Energy so that it became more cost competitive in the energy market. As the LCOE fell, solar PV increased its market share against the dominant fuel sources. In some ways, the ITC contributed to solar PV increasing as a share of the domestic energy mix against oil and gas in some of the same ways that previous federal energy incentives discussed in this paper helped oil and gas increase against earlier energy sources – like burning wood.

Increasing the share of solar PV in the energy mix (and renewable energy sources in general) has many political and policy benefits. State renewable portfolio standards that require utilities to sell a specified percentage or amount of renewable electricity can help a state diversify its energy mix. This diversification can help reduce a state's dependence on limited fossil fuel supplies, promote economic development and job growth, increase resiliency of the grid, and increase efficiency which could translate into consumer savings. These changes can also help to reduce state emissions and improve air quality which can positively improve quality of life.

Given this main finding from my research of barrier reduction, there are two important policy questions worth asking regarding the future of the ITC. First, have barriers to entry now been lowered enough so that solar PV can "stand on its own" moving forward without federal tax incentives like the ITC? Secondly, how much of the electricity sector does society want to come from solar energy sources? The second question, while seemingly ideological in nature, encapsulates several other important policy implications and is addressed more thoroughly in section 6.3. To address the first question, LCOE calculations make it fairly easy to project future cost scenarios with and without the tax credit.

As the Reichelstein and Yorston study showed, the ITC enabled residential and commercial-scale solar PV to achieve cost parity with traditional fossil fuels. At the time of the study (2011), this parity had only been achieved in some parts of the country and utility-scale solar PV had yet to achieve parity with utility-scale fossil fuel sources. A more recent study conducted by the firm Lazard indicates that, in some places, new utility-scale wind and solar PV plants can now be built at a lower LCOE than continuing to operate existing coal plants. As of 2017, the report found:

> *"the mean subsidized LCOE for utility-scale solar fell 72% from $178 per megawatt-hour (MWh) in 2009 to $50/MWh in 2017, while the mean LCOE for wind energy fell 47% from $85/MWh to $45/MWh over the same time span. These declines outstripped the cost trends for natural gas-combined cycle (down 27%), coal (down 8%), and nuclear (up 20%) from 2009 to 2017."* [31]

Despite these positive trends, remember that Reichelstein and Yorston modeled the 30 percent ITC into their LCOE estimates and showed significant price differences in both

[31] The levelized cost of energy 2017 can be accessed from Lazard through (https://www.lazard.com/perspective/levelized-cost-of-energy-2017/).

commercial and utility-scale solar PV when the credit was removed. If the ITC were allowed to expire, the recent gains in parity across the sub-sectors of the solar PV industry could disappear. This was also shown in the 2014 Bloomberg New Energy Finance modeling discussed previously that found the 18GW difference in installed solar capacity from 2016-2021 between the no-ITC extension and extension scenarios.

Taking the idea of reducing barriers to entry one step further, if all federal energy incentives and subsidies were to be eliminated (including the ITC and those to fossil fuel sources), all sources of solar PV would be cheaper than any form of traditional energy production. Figure 5 from the Lazard report below shows the dramatic shift in unsubsidized LCOE for all major U.S. electricity sources from 2009-2017. Parity therefore could be achieved in solar PV without the ITC but only if incentives to the fossil fuel industry were also eliminated. This is an important conclusion to highlight, as a common criticism of the ITC (and similar renewable energy incentives) is that the government should not be picking “winners and losers” in electric power generation. However, given the many incentives available for fossil fuel industries, RE incentives are merely leveling the playing field.

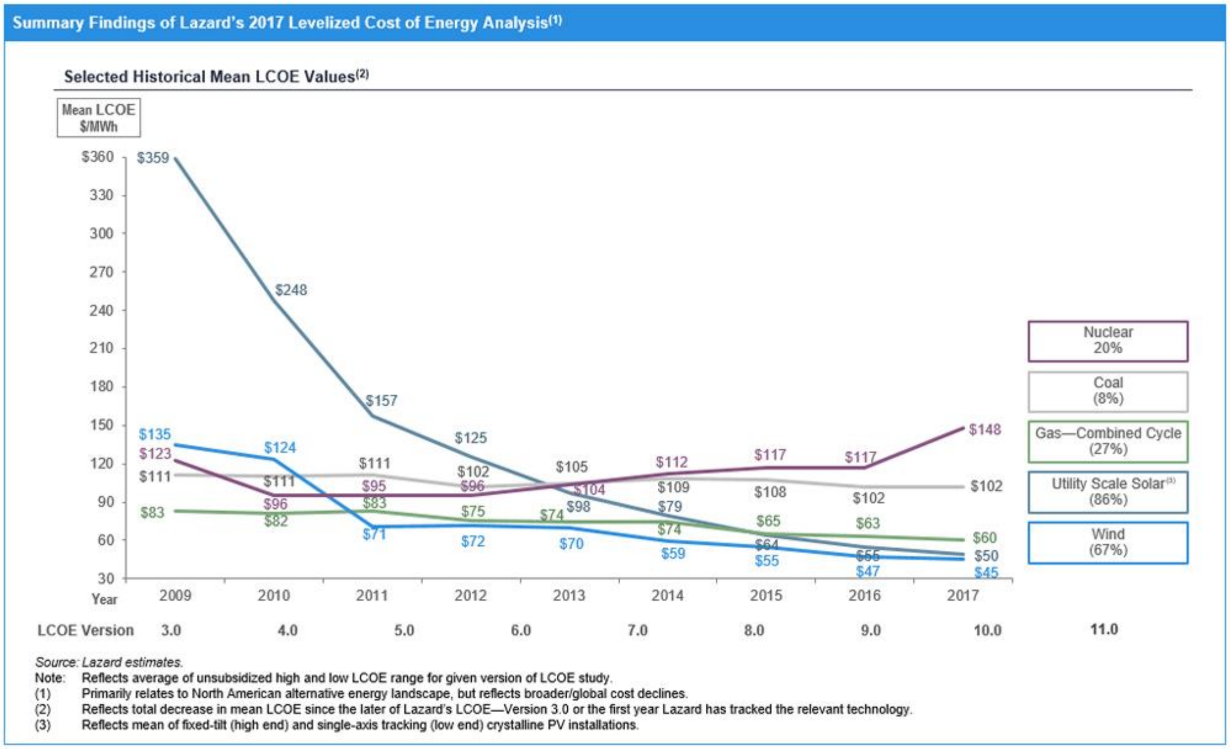

Figure 5. Unsubsidized LCOE for All Major U.S. Electricity Sources (2009-2017).

6.2 Higher Growth Despite Political Obstacles

The second implication from my research mentioned in my introduction is that installed solar PV capacity grew at a higher rate due to the increase of the ITC from 10 percent to 30 percent. After controlling for various price and location factors, my models show this growth was about 140 percent higher from 2006-2015 compared to 1997-2005 (See: Table 3, Model 6 and Table 4, Model 8). My findings are similar to the 2016 report mentioned in my literature review that was prepared for the Office of Energy Policy and Systems Analysis at the U.S. Department of Energy and showed installed capacity of PV grew 60% per year throughout the 2000s and 70% per year so far in the current decade.

This level of growth directly attributed to the increase in the ITC is a remarkable finding of impact for any federal program. This result is made even more remarkable given the ITC's inherent political nature which led to so much fluctuation and uncertainty since 2005. See

Appendix for a detailed overview of political environments since 2005 including oil and gas lobbying expenditures.

The ITC's cost has also been a contributing factor to its political instability. The policy's cost comes from "*foregone tax revenue*" (IE: tax revenue that the U.S. government is not receiving) due to the credit the government grants to companies based on how many kilowatt-hours of solar they generate. The Joint Committee on Taxation estimates that from 2015-2019 the ITC, combined with the PTC for wind, is expected to cost $26.3 billion.[32] This is a large price tag that those opposed to renewable energy tax incentives might point to. However, according to analysis conducted by the Natural Resources Defense Council, the ITC and PTC policies directly resulted in the addition of "*over 220,000 jobs and nearly $23 billion to the U.S. economy in 2017*".[33] Over time, the economic benefits seem to far outweigh the costs.

As discussed throughout this paper, high growth in solar PV directly attributed to the 30 percent ITC is being observed and through at least 2021 large deployment differences are projected between ITC and no-ITC scenarios. However, there is some evidence to support the projection that the ITC's current effect on installed solar capacity may not last in perpetuity. The 2016 NREL study mentioned earlier, that found the ITC to be one of the primary drivers of accelerated solar capacity in recent decades and modeled future solar deployment scenarios through 2030 with and without the ITC, provides evidence to this regard.

The NREL study factors in the graduated phase down of the ITC into modeling that shows the ITC will have a significant impact on increasing solar PV capacity through 2020. Starting around 2022, when the ITC is projected to be permanently limited to just 10 percent for utility,

[32] Present law and analysis of energy-related tax expenditures prepared by the Joint Committee on Taxation can be accessed through (https://www.jct.gov/publications.html?func=startdown&id=4915).
[33] NRDC analysis of the ITC and PTC can be accessed through (https://www.nrdc.org/sites/default/files/engine-growth-renewable-energy-tax-credits-report.pdf).

industrial, and commercial installations and 0 percent for residential, the effect of the ITC is greatly reduced. This can be expected given the credit's reduction. However, the NREL study also shows that around this same time, other drivers of solar deployment converge. These include projected RE cost reductions, expected technological advancements, and increased fossil fuel costs due to potential policies passed between now and then that could make these sources more expensive (such as a carbon tax or increased pollution regulation). Regarding the latter point, the NREL study highlights the EPA's proposed Clean Power Plan (CPP) as one policy driver that was expected to take effect in 2022 and drive accelerated RE capacity. Now that the CPP is in the process of dismantlement by the current administration, it will no longer be this RE driver. However, it's plausible that other policies that increase RE capacity could be implemented between now and the mid-2020s that have a similar impact on converging the ITC and no-ITC scenarios (Mai et al. 2016).

What the NREL study shows, is that the greatest impact of the ITC on solar growth may be being observed right now and that the impact of the credit in the future could be greatly reduced even if it's still available. Solar capacity continues to increase in all projections. But there could be a large disparity in the level of deployment if the policy is ramped down before other convergence factors kick in. Even if it is cost prohibitive to continue the full 30 percent credit all the way through 2030, delaying the phase down by just 2-3 years (until 2025) could have a significant impact on installed solar capacity over the next decade. This impact could have serious ramifications on the future of U.S. electricity generation, efforts to reduce CO2 emissions, and commitments to global climate goals.

6.3 Solar's Future Share of Electricity Generation and Related Emissions Reductions

The third implication from my analysis as well as the second question posed in section 6.1 both return to my secondary hypothesis. My research contributes to a body of evidence that shows the connection between the ITC, yearly installed solar PV capacity, and CO2 emissions. The question of how much energy does society wish to be provided by solar (or any renewable power source) may also have a lot to do with how much society wishes to reduce CO2 emissions. The full extent of the ITC's impact on the future energy mix and emissions depend on many variables referenced throughout this paper. Returning to the NREL study one final time, there are some useful data points to this regard worth evaluating.

Remember that the NREL projections showed continuation of RE tax credits would result in an additional 540 million metric tons lower cumulative energy-sector CO2 emissions from 2016–2030 compared to their scenario without RE credits (under the base natural gas price assumption). Again, this model included the phase down of the ITC so, theoretically, emissions reductions could be much higher if the full 30 percent ITC were continued for additional years (Mai et al. 2016).

To put this level of CO2 reduction into perspective, McDonald's recently announced a plan to reduce their global emissions by 150 million metric tons by 2030. According to their press release, *"this is the equivalent of taking 32 million passenger cars off the road for an entire year or planting 3.8 billion trees and growing them for 10 years".*[34]

Using these metrics, 540 million metric tons lower CO2 emissions would be the equivalent of taking 115 million passenger cars off the road for an entire year or planting 13.6 billion trees and growing them for 10 years. McDonald's is also far from the first company to pledge reductions

[34] McDonald's press release can be accessed through (http://news.mcdonalds.com/news-releases/news-release-details/mcdonalds-becomes-first-restaurant-company-set-approved-science)

from their operations and supply chains. Nearly 700 companies, representing over $15.7 trillion in market cap, have committed to reduce their emissions by a total of 2.31 gigatons (2,310 million metric tons) – equivalent to the total annual emissions of Russia.[35]

According to analysis of the Clean Power Plan conducted by the U.S. Energy Information Agency, the plan (if implemented) was projected to have reduced energy-sector CO2 emissions by up to 625 million metric tons in just the year 2030.[36] Even the most conservative estimates for the combined effect of RE tax credits (including the ITC) and implementation of the CPP on CO2 emissions through 2030 far outweigh the effect of commitments from 700 companies.

This comparison is provided not to pit the private sector against the public. Private-sector investment is critical to facilitate the market transitions that are needed to reach the Paris Agreement's goals of climate stability. But policy decisions made now will also be the catalyst in de-risking and leveraging this investment. There is an important conversation to have regarding the role of the public and private sectors in reducing emissions in line with global climate goals. Neither sector can achieve its full potential and commitments independently but will need to work together in close partnership.

The ITC is one federal policy that has been shown to help drive emissions reductions. The CPP, often referenced to as President Obama's "signature climate policy," would have been another important one.[37] Indeed, compared to RE credits, the projected impact of the CPP in reducing emissions by 2030 would have been much higher. However, as referenced, much of the

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[35] This commitment is part of a pledge created by the We Mean Business coalition that organizes the private sector toward fulfilling global climate goals. The We Mean Business Pledge and list of signor companies can be accessed through (https://www.wemeanbusinesscoalition.org/blog/leading-companies-responding-mahindra-challenge/).
[36] An analysis of the impacts of the clean power plan by the U.S. Energy Information Agency can be accessed through (https://www.eia.gov/analysis/requests/powerplants/cleanplan/).
[37] Cabrera, Yvette. "EPA head announces plan to eliminate Obama's signature climate policy." *Think Progress*. Oct 9, 2017.

implementation of the CPP would not have taken effect until the mid-2020's. This once again supports the conclusion that the greatest impact policymakers can make right now on emissions reductions would be to continue and strengthen existing incentives like the ITC.

From a climate standpoint, the importance of policy action over the next few years cannot be overstated. Research published in the journal *Science* in 2017 is one of many studies that highlight this point and shows that "[global] fossil-fuel emissions should peak by 2020 at the latest and fall to around zero by 2050," to limit global temperature rise to 2°C above pre-industrial levels by 2100 (the goal of the Paris Agreement).[38] Modeling data from the Intergovernmental Panel on Climate Change also shows that a 80-100% global emissions reduction by 2050 is needed to reach the same goal. This means that over the next thirty years, nearly 100% of emissions from energy production and consumption—from cars, planes, trucks, residential and commercial buildings, to industrial facilities—all need to be reduced close to zero. To have just a 66% chance of avoiding 2°C of warming, urgent action on a global scale is required and comprehensive policies need to be introduced immediately according to a recent joint report from the International Energy Agency and the International Renewable Energy Agency. The report also support my previous claim and highlights the importance of the private sector as the "*lifeblood of the global energy system"* but concludes early policy action is necessary to help leverage investment.[39]

It's clear from real-world observation that countries that invest early in policies to incentivize renewable energy set themselves up for tremendous benefits. According to the World Resources Institute, of the 8 million RE jobs around the world, nearly half of them are in China (the country that has invested the most by far), compared to less than one million in the United

[38] Johan Rockström, Owen Gaffney, Joeri Rogelj, Malte Meinshausen, Nebojsa Nakicenovic, Hans Joachim Schellnhuber. "A roadmap for rapid decarbonization." *Science.* 2017; 355 (6331): 1269
[39] Hackman, Will. "The Business Case for U.S. Policy Leadership in Combating Climate Change: Part Two." *Georgetown Journal of International Affairs.* September 18, 2017.

States.[40] It is not only good policy to stimulate RE to satisfy urgent climate objectives but also to create jobs.

6.4 Policy Recommendations

Building from the findings of the previous two sections, this paper makes three policy recommendations regarding my primary hypothesis and the future direction of the ITC and three policy recommendations regarding my secondary hypothesis regarding the ITC's impact on future emissions reductions.

Regarding the first hypothesis – first, the 30 percent credit for installation of (all forms of) solar PV should be maintained at least through the mid-2020s. Second, certain fossil fuel subsidies and incentives should be reduced or eliminated to foster additional market competition in the electric power sector and keep barriers to entry for RE low. Third, a more thorough cost-benefit analysis of the ITC should be conducted on indicators of job creation and economic growth to help reduce political uncertainty and better quantify the program's long-term benefits (now visible).

Without this type of policy intervention at either the federal, state, and/or local levels, the costs associated with expanding solar PV may still be prohibitive in some parts of the country and/or in some sub-sectors of the industry. If states are to achieve their renewable energy portfolio standards and observe the many benefits of increased RE deployment, incentives are still needed to continue the trend of reducing solar PV's LCOE (at least in the short term).

Regarding the secondary hypothesis – first, the ITC should be utilized as a critical compliance mechanism for achieving private-sector corporate emissions reduction goals, state renewable energy portfolio standards, municipal-level commitments, and progress toward

[40] Joel Jaeger, Paul Joffe and Ranping Song. "China is Leaving the U.S. Behind on Clean Energy Investment." World Resources Institute. January 6, 2017.

international commitments. Rather than wait for new federal climate legislation to be passed (a political impossibility at the moment), the ITC is working now and has brought enough benefits to states around the country that a broad coalition of support already exists. Second, the effect of the ITC on local and nation-wide emissions reductions needs to be quantified more in order to support the goals of the first policy recommendation. This could perhaps be done during annual national greenhouse gas inventories the United States completes in compliance with international climate agreements. Third, with increased analysis and data from implementation of my previous policy suggestions, the ITC should be more publicly promoted by government entities to increase utilization of the program by states that may have not yet fully taken advantage of it. There is clearly a dozen or so states that benefit from the credit much more than the mean. California alone makes up nearly half of the entire U.S. residential solar market.[41] To reach a more balanced effect of the program, participation needs to increase.

VII. CONCLUSION

The United States is resource rich with one-fifth of the entire world's coal reserves and 34 percent of global technically-recoverable natural gas. [42][43] The U.S. is the largest producer of natural gas and oil in the world (including crude and petroleum hydrocarbons).[44][45] It is entirely plausible that new policies under the current administration (or any future administration) to increase fossil

[41] Pyper, Julia. "New U.S. Residential Solar Capacity Down 17% Year-Over-Year for Q1." *Greentech Media.* May 17, 2017.
[42] U.S. Energy Information Agency data on how much coal is in the United States can be accessed through (https://www.eia.gov/energyexplained/index.cfm?page=coal_reserves).
[43] U.S. Energy Information Agency data on how much natural gas is in the United States can be accessed through (https://www.eia.gov/tools/faqs/faq.php?id=58&t=8).
[44] U.S. Energy Information Agency data on top oil producing countries can be accessed through (https://www.eia.gov/tools/faqs/faq.php?id=709&t=6).
[45] U.S. Energy Information Agency data on the United States as the world's top producer of petroleum and natural gas hydrocarbons can be accessed through (https://www.eia.gov/outlooks/ieo/exec_summ.php).

fuel production could correct production declines observed in recent decades. Global net electricity generation is also projected to increase by 45% by 2040 as countries grow and industrialize.[46] Now that the U.S. has become an exporter of coal, oil, and natural gas, domestic fossil fuel production may increase to meet global demand and even if domestic demand decreases.

The ITC's effect on installed solar PV capacity has grown rapidly since its increase to 30 percent in 2005. However, solar PV was still only 1.2% of U.S. electricity generation in 2017 compared to 63% from fossil fuel sources.[47] If the local, state, and/or federal policymakers wish to incentivize a more rapid and economic approach to aggressive emissions reduction in line with long-term climate goals, and to keep pace with global energy demand increases over the next few decades, additional policies will be needed. Some options this paper has mentioned include continuing existing policies that are working and eliminating fossil fuel subsidies to level the playing field for other energy sources to supply a larger share of the market. Other options could include a carbon price and/or carbon market trading system and incentives that target emissions reductions in other sectors of the economy such as transportation and industrial agriculture.

What my research and similar research indicates is that the ITC has been an important and successful policy lever for decades in the growth of the domestic solar PV industry. The data is clear despite ideological or political objections. Nevertheless, research shows that continued exponential growth in this industry without these types of policy levers is not certain. If renewable energy tax incentives were to be eliminated and/or fossil fuel incentives increased, the positive trends in solar's LCOE could potentially vanish. The U.S. solar PV industry still struggles to retain a foothold in the market and it may not take much for the industry to experience a downturn. GTM

[46] U.S. Energy Information Agency International Energy Outlook 2017 can be accessed through (https://www.eia.gov/outlooks/ieo/exec_summ.php).
[47] U.S. Energy Information Agency data on U.S. electricity generation by energy source can be accessed through (https://www.eia.gov/tools/faqs/faq.php?id=427&t=3).

Research and the Solar Energy Industries Association recently found that in the third quarter of last year, solar PV installations were down 51 percent compared to the same time period the previous year.[48] This decline was attributed to political uncertainty and a sluggish housing market and was projected to only be short term. Yet, it illustrates how tenuous the market can be and indicates the need for policymakers to renew their commitments to incentives like the ITC if renewable energy is to secure a significant share of domestic energy generation over the next few decades.

VIII. APPENDIX

8.1 Definition of Terms

A "tax credit" is defined as "an amount of money that is subtracted from taxes owed."[49] This is different from a "tax deduction" which lowers an individual's or business's taxable income. A tax credit is a dollar-for-dollar reduction in an entity's tax bill and, as such, has real financial value to that entity as well as real cost to the federal, state, or local entity providing the credit. Tax credits, as well as tax deductions, can be a very important mechanism for investment, savings, or income for the receiving entity.

The "ITC" is referenced several different ways throughout this paper. This is due to the nature of its evolution as a policy tool that has undergone many revisions. This paper's primary use of the ITC refers to the post-2005 ITC iteration, also known as the "Solar Investment Tax Credit." The ITC existed in other forms prior to 2005 however its effect on the solar industry changed significantly when the credit for solar installations was expanded from 10 percent to 30

[48] Danigelis, Alyssa. "GTM Research Reports US Solar Installation Slowdown." *Energy Manager Today.* December 18, 2017.
[49] A Merriam-Webster definition of "tax credit" can be accessed through (https://www.merriam-webster.com/dictionary/tax%20credit?src=search-dict-hed).

percent. This change was so significant that, for the purposes of my research, 2005 is referred to as the "introduction" of the "solar ITC" (as the industry has known it for over the last 10 years).

The "Levelized Cost of Electricity" (LCOE) is mentioned a few times throughout this thesis. LCOE is a calculation that averages the total cost to build and operate an energy generating system divided by the system's total lifetime energy output. In other words, LCOE produces a mean value that must be reached in order for a project to break even. For instance, if the LCOE of a commercial solar PV power plant is $100 per megawatt-hour (MWh), then that plant will need to charge at least $100 MWh to consumers to break even.

8.2 Detailed Description of Oil and Gas Lobbying Expenditures Since 2005

As fossil fuels have declined as a share of total U.S. energy production and tax incentives that used to solely benefit these industries are restructured to engender competition, fossil fuel companies have increasingly sought to retain their historical dominance. Since 2005, the oil and gas industry has spent over $1.6 billion in direct campaign contributions to political candidates for federal public office, according to the Center for Responsive Politics.[50] The coal mining industry has spent over $170 million since 2005 on direct campaign contributions.[51] These numbers do not include state or local political campaign contributions or the funding of third-party advocacy organizations that independently engage in political influence. For instance, during the 2012 presidential election cycle, third-party political spending by a network of organizations connected to Koch Industries (which has well-documented ties to the fossil fuel industry) totaled $412

[50] Lobbying contribution database can be accessed through (https://www.opensecrets.org/lobby/indusclient.php?id=E01&year=2016).
[51] Lobbying contribution database can be accessed through (https://www.opensecrets.org/lobby/induscode.php?id=E1210&year=2017).

million.[52] In a 2015 interview with National Public Radio, Koch Industries' chairman and CEO Charles Koch stated that his network might spend up to $750 million just during the 2016 presidential election cycle -- with most of this funding coming through these third-party advocacy organizations.[53]

The exponential increase in political spending in recent years has been observed across many issues and has benefitted both Democratic and Republican candidates for public office. But when observing political contributions by fossil fuel industries and their supportive groups, the majority of contributions made benefit the Republican party. Out of the nearly $105 million spent in direct campaign contributions by the oil and gas lobby in the 2016 election cycle, 87.9% went toward Republican candidates and 12% went toward Democrats.[54] The total amount the oil and gas lobby has spent in election cycles has steadily risen over the years, particularly in those cycles that correspond with the Presidential election: $27.5 million (2006), $40 million (2008), $79.8 million (2012). And the disparity between Republican and Democrat recipients has remained consistent: 81.7% to 18.7% (2004), 77.6% to 22.4% (2008), 89.1% to 10.8% (2012), respectively.[55] These are all federal spending totals do not take into consideration millions more spent in state and local elections.

The spending disparities indicate a difference in favorability from fossil fuel industries toward Republican and Democrat candidates for public office. These political differences can have real policy implications and this effect has been observed in the fluctuations of renewable energy tax credits like the ITC over time. It is worth considering these dynamics when formulating new

[52] Analysis of Koch Industries spending by *The Nation* can be accessed through (https://www.thenation.com/article/koch-brothers-spent-twice-much-2012-election-top-ten-unions-combined/).
[53] NPR interview with Charles Koch can be accessed through (https://www.marketplace.org/2015/10/21/business/corner-office/full-interview-charles-koch).
[54] Lobbying contribution database can be accessed through (https://www.opensecrets.org/overview/industries.php).
[55] Lobbying contribution database can be accessed through (https://www.opensecrets.org/overview/industries.php?cycle=2012).

polices as they may not only impact the ability to pass renewable policy incentives but also to what extent incentives are utilized. For instance, the top five state markets for added solar PV capacity in 2017 were California, New York, Maryland, New Jersey, and Arizona.[56] Four out of these five states have a much higher percentage of elected representatives from the Democratic party than Republican party.

[56] U.S. solar market analysis by GTM Research can be accessed through (https://www.greentechmedia.com/research/subscription/u-s-solar-market-insight#gs.iqNw7Cc).

IX. BIBLIOGRAPHY

1. “Solar ITC Impact Analysis.” Solar Energy Industries Association. 2017.
2. Schlichting, Kerry. "Federal Programs Enable Unprecedented Solar Power Deployment." The Pew Charitable Trusts. 2015.
3. "Leveraging Federal Renewable Energy Tax Credits." U.S. Department of Energy, Energy Efficiency and Renewable Energy. 2016.
4. Aanesen, Heck, and Dickon Pinner. "Solar power: Darkest before dawn." McKinsey & Company. 2012.
5. “IRS and Treasury Release Notice on New Energy Credits Regulations.” Deloitte. 2015
6. “General Explanation of the Tax Reform Act of 1986.” Joint Committee on Taxation, Congress of the United States. 1987.
7. “Tax Reform Act of 1986.” U.S. Government Printing Office. 1986.
8. “The Energy Policy Act of 1992.” U.S. Government Printing Office. 1992.
9. “The Energy Policy Act of 2005.” U.S. Government Printing Office. 2005.
10. “Solar Investment Tax Credit.” Solar Energy Industries Association. 2017.
11. Hart, David and Birson, Kurt. “Deployment of Solar Photovoltaic Generation Capacity in the United States.” Schar School of Policy and Government, George Mason University. Prepared for Office of Energy Policy and Systems Analysis, U.S. Department of Energy. 2016.
12. Worland, Justin. “The Tax Reform Bill Could Hurt Wind and Solar Power.” *Time.* November 30, 2017.
13. “Consolidated Appropriations Act, 2016.” U.S. Government Printing Office. 2016.
14. “Investment tax credit for solar power.” *Energy Sage.* 2017

15. Wiser, Bollinger, Barbose, Ryan, et al. "Using the Federal Production Tax Credit to Build a Durable Market for Wind Power in the United States." The Electricity Journal, vol. 20, no. 9, 2007, pp. 77–88.

16. Comello, Stephen, and Stefan Reichelstein. "The U.S. investment tax credit for solar energy: Alternatives to the anticipated 2017 step-Down." Renewable and Sustainable Energy Reviews, vol. 55, 2016, pp. 591–602.

17. Mai, Cole, et al. "Impacts of Federal Tax Credit Extensions on Renewable Deployment and Power Sector Emissions." National Renewable Energy Laboratory. 2016.

18. Hymel, Mona. "The United States' Experience with Energy-Based Tax Incentives: The Evidence Supporting Tax Incentives for Renewable Energy." Law Journal Library. Loyola University Chicao Law Journal Vol. 38. 2006.

19. Reichelstein, Stefan, and Michael Yorston. "The Prospects for Cost Competitive Solar PV Power." SSRN Electronic Journal, 2012, doi:10.2139/ssrn.2182828.

20. Lazzari, Salvatore. "Energy Tax Policy: History and Current Issues." Congressional Research Service. June 10, 2008.

21. "Impact of tax credit extensions for wind and solar." Bloomberg New Energy Finance. 2015.

22. Durkay, Jocelyn. "State Renewable Portfolio Standards and Goals." National Conference of State Legislatures. 2017.

23. "U.S. Solar Market Sets New Record, Installing 7.3 GW of Solar PV in 2015." Solar Energy Industries Association. 2016.

24. Fang, Lee. "The Koch Brothers Spent Twice as Much on the 2012 Election as the Top Ten Unions Combined." *The Nation.* March 7, 2014.

25. Ryssdal, Kai. "Full interview: Charles Koch." *Marketplace,* National Public Radio. October 21, 2015.

26. "U.S. Solar Market Insight." GTM Research. 2017.

27. "Present Law and Analysis of Energy-Related Tax Expenditures." Joint Committee on Taxation, Congress of the United States. 2016.

28. "Engine of Growth: the extensions of renewable energy tax credits will power huge gains in the clean energy economy." Natural Resources Defense Council. 2017.

29. "Levelized Cost of Energy 2017." Lazard. 2017.

30. "Analysis of the Impacts of the Clean Power Plan." U.S. Energy Information Agency. 2015.

31. "How Much Coal is in the United States?" U.S. Energy Information Agency. 2018.

32. "How much natural gas does the United States have, and how long will it last?" U.S. Energy Information Agency. 2018.

33. "What countries are the top producers and consumers of oil?" U.S. Energy Information Agency. 2018.

34. "United States remains the world's top producer of petroleum and natural gas hydrocarbons." U.S. Energy Information Agency. 2017.

35. "International Energy Outlook 2017." U.S. Energy Information Agency. 2017.

36. "What is U.S. electricity generation by energy source?" U.S. Energy Information Agency. 2018.