DO CLIMATE CHANGE AT-RISK STATES GENERATE MORE RENEWABLE ENERGY

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By

Andrew V. Smith, B.S., B.B.A

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Andrew V. Smith, B.S., B.B.A.

Thesis Advisor: Andrew Wise, Ph.D.

ABSTRACT

As the risk of climate change grows across the planet, reducing greenhouse gases will become increasingly important. However, damage from climate change is not felt equally across the U.S. Some areas feel the effects of it much more harshly than others. Using fixed effect regressions for the years 2001 to 2014, I estimate the relationship between renewable energy production and storm damages associated with climate change at the state level. My hypothesis tests whether states that are at risk due to the effects of climate change produce more renewable energy. I find that states that states with higher levels of damages from storms linked to climate change do produce more renewable energy, on average. In testing my hypothesis I also examined which state level policies have the biggest impact on renewable energy production and conclude that the Mandatory Utility Green Power Option is an effective program in producing renewable energy. I propose that states that are directly impacted by climate adopt this policy to help reduce greenhouse gases and potential future damages.
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Introduction

This thesis focuses on the growth of renewable energy as it pertains to climate change. It adds to the current literature about the organization of the energy industry within the United States, carbon dioxide (CO₂) emissions and climate change, and the relationship between renewable energy and carbon dioxide emissions. My hypothesis tests whether states that are at risk due to the effects of climate change produce more renewable energy.

Renewable Energy is defined as hydroelectric power, geothermal, solar, wind and biomass. Renewable energy production in the United States has increased 57 percent from 6,101 trillion British Thermal Units (Tbtu) in 2000 to 9,575 Tbtu in 2015 (EIA 2016). At the same time, U.S. consumption of renewable energy has seen a similar growth. Many believe that renewable energy is a way to stem the current growth in greenhouse gas emissions.

A major factor in climate change is the amount of greenhouse gases released into the atmosphere. The United States along with China are the largest emitters in the world. China emits slightly over 25 percent of the world’s greenhouse gas gases while the Unites States emits over 14 percent (EPA). In 2015 the U.S. energy sector released 5,271 million metric tons of carbon dioxide, with 28 percent of these emissions coming equally from coal and natural gas and 43 percent coming from petroleum. (EIA) In December 2015, as part of the Paris Climate Talks, the U.S. pledged to reduce emissions to 26 to 28 percent below 2005 levels by 2025 (Tollefson). Reducing carbon emissions has become particularly important as the United States arguably has begun to see the impacts of these emissions.

Since 2002, we have seen four of the top five costliest storms in U.S. history. Hurricane Katrina, Superstorm Sandy, and Hurricanes Ike and Ivan cost over $250 billion (CPI adjusted)
These storms made landfall in many disparate parts of the U.S. Hurricane Katrina in 2005 caused damage along the Louisiana, Mississippi, and Alabama coastlines. Sandy, in 2012, struck the Northeast with damage ranging from Washington, DC through New York, New Jersey and Connecticut. Hurricane Ike in 2008 caused extensive damage to the Texas coastline while Hurricane Ivan caused damage in Alabama and Florida. The economic damage caused by these storms is substantial, and I look to see if any of these states have taken action to try and reduce their carbon footprint and shift their energy makeup towards renewables. In this paper I argue that these storms are a direct result of the changing climate.

As U.S. efforts to reduce carbon emissions grow, renewable and emission-free sources of energy could become an important part of the nation’s future. This paper discusses the growth of the coal, oil, and natural gas industries and how experience in these industries relates to the growth of renewable energy industries, particularly in climate change effected areas. I also look at the relationship between oil, gas, and coal prices and their impact on renewable energy generation.

Using data from the U.S. Energy Information Agency on energy generation at the state level, as well data on as oil, natural gas, and coal prices going back to 2001, I look at the growth in renewable energy generation throughout the United States. Using multivariate regression I estimate the difference between renewable energy production in climate impacted states versus states that have not felt the brunt of climate change.

I try to determine if states affected by climate change increase their renewable energy production. I find that damages at the state level from storms associated with climate change do have a positive relationship with renewable energy production. I also look into the question of
which policies lead to a state producing more renewable energy and determine that the Mandatory Utility Green Power Option is positively correlated with renewable energy production as well as the price of coal. In using these results I formulate policy options that states should consider to reduce the threat of climate change.

This paper is organized in seven sections. A background section covers the energy industry in the United States, the impacts of climate change, and the makeup of the U.S. renewable energy sector. A second section reviews the relevant literature on this topic. And subsequent sections go through my models and data analysis and review my results, conclusions, and policy suggestions.
Background

History of Energy in the United States

While the United States has always possessed large reserves of natural gas, oil, and coal since the country was founded, for a long time technology had not advanced to extract these resources in an efficient way. At the country’s founding, fuel wood and water mills helped provide necessary energy. Transportation was driven by wind at sea and animals on land (EIA).

The energy industry began to evolve in the early 19th century as coal became the driving force behind U.S. industry. As the country began to expand west, massive coal deposits were found and, with the growing railroad industry, coal became the primary source of energy. The metals industry needed coal to create the steel necessary for laying thousands of miles of track, and coal increased the range of trains. As the transportation and industrial sectors grew so did the use of coal (EIA).

By the end of World War I, coal accounted for 75 percent of total U.S. energy use (EIA). But by the early 20th century, petroleum had arrived as a new energy competitor to coal. In 1901, the discovery of the Spindletop Oil Field in Texas combined with the growing number of automobiles led to a boom in petroleum use. And following World War II, petroleum became the country’s preeminent energy source. The transportation industry shifted from coal-powered trains to petroleum powered cars, trucks, and airplanes. Coal, however, did not become obsolete, as electric utilities still relied on it to provide household power across the country (and still do) (EIA).
The third major fossil fuel that provides energy in the United States is natural gas. In recent years natural gas has become one of the preeminent sources of energy. Throughout the 20th century natural gas rose in prominence as a competitor to coal. Natural gas can be drilled both on and offshore and must be treated and purified into the components that can be used to generate power. Once purified it is transported via pipelines to utility companies where it is then distributed to power and heat homes and businesses. In the 1970s, however, the U.S. began to hit a natural gas production peak. By 1973 there were significant gas shortages due to an increase in oil prices and therefore an increase in demand for natural gas which was hard to meet using legacy technologies.

The shale gas revolution changed the entire natural gas market. Shale gas is natural gas that is drawn from shale deposits located thousands of feet below the earth’s surface. Most of the deposits are located in Texas, the south, the northeast, the mid-west, and the Rocky Mountains. At the beginning of the 21st century, very little natural gas came from these shale deposits. However, as the technology to drill for this gas improved, the production and demand for natural gas increased sharply, and the price decreased as well (Joscow 2012). As of April 2016 natural gas accounts for 33 percent of the electricity generated in the United States matching coal as the most produced energy source in the country.

**Impacts of Climate Change**

Man-made climate change is tied particularly to Greenhouse Gases (GHGs) and most particularly CO₂. The earth’s temperature is determined by how much of solar radiation is absorbed by the earth and how much is reflected back into space. Approximately one-third of solar energy is reflected back into space while the rest is absorbed by the land and oceans
The earth’s atmosphere is made up of water vapor, CO₂, methane and nitrous oxide and these, grouped together, are what are known as GHGs. These gases create the greenhouse effect which absorbs some of the radiation from the sun and in turn warms the planet (Maslin).

While GHGs are not bad for the environment, per se, an overabundance of them is. In the late 18th century, as industrial revolution began, industries across the world burned fossils fuels (oil and coal) which released CO₂ and methane back into the atmosphere. These fuels, which are essentially fossilized sun energy, led to the growth of GHGs in the atmosphere and produced a stronger greenhouse effect. With the stronger greenhouse effect, more of the sun’s radiation that previously was reflected back into space stayed on earth and began to heat up the planet (Maslin).

University of Chicago oceanographer David Archer says that much of the CO₂ lasts in the atmosphere for a few centuries with some of it staying there forever (Inman). This implies that warming from GHG emissions will be long-lasting. Even if we ended all CO₂ emissions today the remnants would still be around for centuries (Inman).

The release of GHGs has caused temperature rises across the globe. Moreover in the Arctic temperature increases are nearly double that of the global average change. This can have devastating effect on the sea ice cover. The sea ice cover affects arctic temperatures causing heat transport across the ocean and may be one of the causes behind the increased number and intensity of extreme weather events associated with global warming. Sea ice decline also affects hemispheric temperature and equator-to-pole temperature difference which is a major indicator of global warming (Cvijanovic).
Effects will be varied and widespread. Marcia McNutt writes, “environmental changes brought on by climate changes will be too rapid for many species to adapt to, leading to widespread extinctions. Even species that might tolerate the new environment could nevertheless decline as the ecosystems on which they depend collapse.” (McNutt)

However, the EPA concludes that climate change will effect geographic locations differently. For example, states in the southern and western regions of the U.S. are more sensitive to coastal storms, drought, air pollution and heat waves, while the Mountain West region will likely face water shortages and increased wildfire (EPA). The EPA concluded that even if these regions shift their energy production, the effects of climate change will still harm them more than other parts of the country. Conversely, if the states that are unaffected by climate change don’t adjust their energy production then they still will not feel the harmful effects.

**Renewable Energy in the United States**

In 2015, renewable energy accounted for over 13.4 percent of electricity produced in the U.S. and 11.1 percent of total U.S. energy generation (EIA). Types of renewable energy include solar, thermal, wind, hydropower, tidal, and biomass. To be renewable, sources must be continually replenished in nature and derived directly from the sun, indirectly from the sun or come from other natural movements and mechanisms in the environment (Ellabban). Since 2008, U.S. reliance on renewable energy has grown, the use of old technologies, like hydro, and new technologies, like solar and wind, have risen quickly due to lower costs and new opportunities. According to Ellabban, global electricity generation is expected to grow 270 percent between 2010 and 2035, from 4.2 billion MWh to 11.3 billion (Ellabban).
The different kinds of renewable energy have different characteristics. For example, biomass, the conversion of organic material such as plants, trees, and crops into energy, is both renewable and sustainable, but it does share similarities with fossil fuels. Thus, biofuels can be transported and stored and allow for on-demand energy consumption, which differs from other renewable sources such as wind and solar which can only produce energy during certain periods. The issue with biomass is that they have low energy densities and price of this fuel generated electricity does not offset the full cost of producing and transporting the fuel (Ellabban).

Generation of geothermal energy uses high, intermediate and low temperature geothermal fields which are generally associated with recent volcanic activity. In 2012, the U.S. had just 3,400 mW of geothermal energy which made up almost 30 percent of global output but only 0.4 percent of U.S. energy generation (Ellabban).

Hydropower is an older form of renewable energy dependent on the flow of water in rivers, and usually generated by dams. Hydropower projects can be massive projects such as the Three Gorges Dam in China which generates between 80,000,000 and 100,000,000 mWh/year and the Alder Dam in Washington State that generates 197,830 mWh/year. These dams can be used for storage by creating a reservoir or pure generation according to how the river flows. The technology is extremely efficient, with 90 percent of the energy produced going straight into potential consumption. However, hydropower does have drawbacks, in that the reservoir created behind dams can displace people and changes the local ecosystem (Ellabban).

Solar energy uses the sun to provide electricity via solar photovoltaic (PV) systems. PV converts energy from the sun directly into electricity from the PV cell. PV technologies are
efficient and can be produced in large batches, helping to drive down the cost. PV also is able to use diffused sunlight, and so does not require the sun to be shining directly on the panel to generate electricity. Solar can be connected to the grid to create a centralized area of energy generation or can operate off-grid, allowing the end user to access the electricity directly from the PV module. However, storage during periods without sunlight remains a challenge (Ellabban).

Wind energy draws the power from wind driving turbines to make electricity. These turbines were first developed in the early 20th century and by the end of the 1990’s, wind power emerged as one of the most important sustainable energy resources. Wind energy uses the kinetic energy of moving air and converts it to electric energy. However, the turbine captures less than half of the available energy, since the lack of storage ability causes the whole system to lose energy if it is not consumed (Ellabban).
Literature Review

I review the literature surrounding climate change, renewable energy, greenhouse gases, and storms related to climate change. This literature explores the link between greenhouse gases and how the greenhouse effect impacts the climate. Following this I show the connection between climate change and climate associated weather, such as droughts and hurricanes. On top of this I present an analysis of renewable energy sources and how they are the best form of energy in terms of GHG emissions. Finally I discuss how state level policy can influence the use of renewable energy as a major energy source.

Panwar writes that the most important environmental problem related to energy is global climate changes and that the increasing concentration of greenhouse gases such as \( \text{CO}_2 \), \( \text{CH}_4 \), chlorofluorocarbon (CFCs), halons, \( \text{N}_2\text{O} \), ozone and peroxyacetylnitrate in the atmosphere is trapping heat radiated from the earth and causing the surface temperature of the earth to rise (Panwar). \( \text{CO}_2 \) levels have increased 31 percent in the past 200 years, and the earth’s surface temperature has increased by 0.4 to 0.8 °C in the last century alone. The increase in global temperature has caused the mean sea level to rise at an annual rate of one to two millimeters. However, the increase in GHGs has caused the Arctic sea ice to thin by 40 percent and decrease its extent by 10 to 15 percent since 1950 (Panwar).

Amponsah, et al. studied the life cycle of the various sources of renewable energy from hydropower to solar to waste. Their life cycle analyses focused on fuel extraction, transportation, conversion, transmission and distribution, waste disposal and the dismantling of the facilities. They concluded that GHG emissions occur upstream generally in the commissioning and decommissioning of plants. To compare to fossil fuels, fuel consumption during operation of the
facility makes up around 83 percent of GHGs. For hydropower, solar and wind systems the total GHG emissions comes almost entirely from infrastructure construction, raw material acquisition, manufacturing, and transportation. Although GHGs are emitted during the creation of renewable energy from various sources, even in the worst case scenarios, renewable energy emissions are lower than conventional sources (Amponsah).

Greenhouse gases play a major role in the heating up of the planet. Carbon dioxide concentration has been one of the major factors that have caused a warming of the earth over the past 50 years. The emissions of the heat-trapping gases have caused a thickening of the blanket which is causing the temperature of the earth to rise (Karl, et al.). Since 1970, global average temperatures have increased and this trend coincides with the melting of the Arctic Sea ice and the retreat of glaciers on every continent, reductions in snow cover, early blooming of plants and increased melting of the Greenland and Antarctic ice sheets. On top of that, the troposphere is warming and the stratosphere is cooling. Karl et al. write, “this pattern of tropospheric warming and stratospheric cooling agrees without understanding of how atmospheric temperature would be expected to change in response to increasing greenhouse gas concentrations and the observed depletion of stratospheric ozone.” (Karl, et al.) The evidence is clear that global warming or climate change is primarily influenced by human related increases in greenhouse gases.

With a warmer globe come the damages associated with a changed climate. Following the 2003 heatwave in Europe, Peter Stott investigated what impact climate change had on the heatwave itself. He looked into the mean decadal summer temperatures and concluded that human induced climate change is statistically significant and therefore responsible for a
significant fraction of the observed European summer warming. (Stott) Stott also concluded that
that by the 2040s half, of the summers will be warmer than the 2003 heatwave (Stott).

Loukas, et al. reviewed eight papers looking into the links between climate change and
extreme weather events. Their aim was to present results on extreme weather events including
the assessment of the risk posed by the extreme events and the expected changes in the frequency
and intensity of these events (Loukas, et al.). Planchon, et al. found that over the 1958 to 2005
time period precipitation in Brittany, France occurred more frequently associated with westerly
or southerly circulation (Planchon , et al.). Vasiliades, et al. investigated the impact of climate
change on droughts in Thessaly, Greece during 1960-1990 and 1990-2002. Their results showed
that climate change will have a major impact on droughts (Vasiliades, et al.).

Sauerborn writes that while extreme events are rare, observations since 1950 show that
the frequency, intensity, spatial extent, and duration of some extreme weather and climate events
have grown and will continue to grow with climate change. He concludes that the planet will see
increases in the frequency of heavy precipitation, an increase in average tropical cyclone
maximum wind speeds, an intensification of droughts, and possible changes in floods
(Sauerborn).

Shrimali finds that policy plays an important role in the penetration of renewable energy,
and that whether the policies are command-and-control, market-based, or incentive based, they
all can be used to allow power producers to take advantage of the renewable power market. He
concludes that the policy mechanisms could be even more useful to state governments if U.S.
Climate Change/Carbon Emissions policy becomes a reality (Shrimali).
The two policies that the literature shows are most effective are the renewable portfolio standards and the Mandatory Green Power Option. Delmas, et al. review the Mandatory Green Power option and showed that this policy, which requires utilities to provide green electricity to their customers, is an effective policy in increasing renewable capacity (Delmas, et al.). Bird, et al. concluded in their analysis of state level renewable energy policies that renewable portfolio standards are the best policy a state can use to promote wind energy (Bird, et al.).

My study contributes to this literature by using a dataset that explores the relationship between climate induced natural disasters and renewable energy production in the U.S. at the state level. In my dataset, I control for various outside influences on production such as gas, oil and coal prices, state level financial incentive policies, and production of other forms of energy. Understanding whether there is a link between climate change and state level renewable energy production will help us design the best policies and determine where to implement them to stem the release of greenhouse gases. In looking through the most effective policies the literature shows that a renewable portfolio standard and the mandatory utility green power option are the most effective state policies in promoting renewable energy.

I next present the theoretical model that informs my analysis.
Theoretical Model

The studies I present in my literature found that there is a link between Greenhouse Gases and the amount of damage due to storms associated with climate change, and also that renewable energy is the energy source that emits the lowest amount of GHGs in the atmosphere. To examine how states react to these considerations, my theoretical model, shown below, explores the relationship at the state level between renewable energy production and damage from major storms associated with climate change:

\[ \text{REP} = f(D, FFP, P, EP, e) \]  

In the model, REP is renewable energy production, D is the amount of state level storm damages, FFP is other fossil fuel production (Coal, Petroleum, Natural Gas), P is an indicator of the state energy policy, EP is the price of fossil fuels, and e is random error.

The model assumes that renewable energy production will change based on whether a state has suffered damages from a major storm during the time period analyzed. My model controls for storm type as some storms may be more associated with climate change than others. I also control for specific policy type to see if one incentive promotes renewable energy production more than others. Finally, I control for region to understand if certain regions have a susceptibility to storm damage and renewable energy production.

The model allows me to explore how states at risk from climate change react to major storms. My model assumes that major storms are a product of climate change. By first seeing if there is an effect I can also explore which types of policies have the greatest incentive to get states to change their energy production mix.

In the next section, I detail the empirical model I estimate.
Empirical Model

I estimate three fixed effects equations to determine the impact of climate change via state level storm damages on renewable energy production at the state level. The models also control for two types of state level renewable energy policy as well as the prices of fossil fuels and heating and cooling degree days.

Renewable Energy Production, Renewables, expressed in mWh, is the dependent variable in my analysis. The key independent control variables are CrudeOilPrice, which is the price of oil; NaturalGasPrice, which is the price of natural gas; and CoalPrice, which is the price of coal. The key policy independent variables are MandatoryUtilityGreenPowerOpdum, which is an indicator variable that indicates whether the state has a Mandatory Utility Green Power Option policy in place, and RenewablesPortfolioStandarddum, which indicates whether a state has a renewables portfolio standard policy in place. Additional control variables adjust for weather-related factors: CoolingDays is the number of degrees that a day’s average temperature is above 65 degrees Fahrenheit. HeatingDays is the number of degrees that a day’s average temperature is below 65 degrees Fahrenheit (NOAA). Damages expressed in 2014 constant dollars is the main independent variable of interest.

Model 1 uses a fixed effects approach with state as the panel variable, (represented by $\alpha$) to test whether or not damages due to climate change have an effect on renewable energy production. The model is specified as:

\[
\text{Renewables} = \beta_0 + \alpha + \beta_1 \text{Damages} + \beta_2 \text{CrudeOilPrice} + \beta_3 \text{NaturalGasPrice} + \beta_4 \text{CoalPrice} + \beta_5 \text{MandatoryUtilityGreenPowerOpdum} + \beta_6 \text{RenewablesPortfolioStandarddum} + \beta_7 \text{CoolingDays} + \beta_8 \text{HeatingDays} + \epsilon
\]
Model 2 also uses fixed effects regressions to test whether or not damages due to climate change have an effect on renewable energy production, but this removes \textit{CrudeOilPrice} and \textit{RenewablesPortfolioStandarddum} due to likely collinearity between the three fossil fuel prices and the two state policy variables. This model is specified as:

\[
\text{Renewables} = \beta_0 + \alpha + \beta_1 \text{Damages} + \beta_2 \text{NaturalGasPrice} + \beta_3 \text{CoalPrice} + \beta_4 \text{MandatoryUtilityGreenPowerOpdum} + \beta_5 \text{CoolingDays} + \beta_6 \text{HeatingDays} + \varepsilon
\]

Model 3 uses fixed effects regressions as above, but adds back in \textit{RenewablesPortfolioStandarddum} to ensure any effects for the two policies is a real effect and not due to collinearity, or model selection. This model is specified as:

\[
\text{Renewables} = \beta_0 + \alpha + \beta_1 \text{Damages} + \beta_2 \text{NaturalGasPrice} + \beta_3 \text{CoalPrice} + \beta_4 \text{MandatoryUtilityGreenPowerOpdum} + \beta_5 \text{RenewablesPortfolioStandarddum} + \beta_6 \text{CoolingDays} + \beta_7 \text{HeatingDays} + \varepsilon
\]

Table 1 describes the variables in these equations. In each equation, I expect renewable energy production to increase as damages from storms increase, causing the coefficient for \textit{Damages} to be positive. I also expect there to be a statistically positive relationship between oil, coal and gas prices and renewable energy production. As discussed in my literature review, Renewable Portfolio Standards and Mandatory Utility Green Power Options have been shown to have an impact on renewable energy production so I expect these variables will have positive coefficients. Finally, as the temperature deviates from 65 degrees Fahrenheit there will be a greater demand for energy and thus more energy produced; I expect the coefficients for \textit{CoolingDays} and \textit{HeatingDays} to be positive too.
The model as a whole should give a good indication of if and how much of an effect
storm damages as a result of climate change will have on renewable energy production. As all of
the models test the same basic assumptions, the coefficients should be consistent across all three
models.

**Table 1: Variable Descriptions.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Renewables</strong></td>
<td>Renewable Energy Production at the state level in mega Watt hours</td>
</tr>
<tr>
<td><strong>Damages</strong></td>
<td>A continuous variable that measure the cost of damages from storms at the state great the one billion dollars, in constant 2014 dollars</td>
</tr>
<tr>
<td><strong>CrudeOilPrice</strong></td>
<td>Price of Crude Oil ($/barrel)</td>
</tr>
<tr>
<td><strong>NaturalGasPrice</strong></td>
<td>Price of Natural Gas ($/MMBtu)</td>
</tr>
<tr>
<td><strong>CoalPrice</strong></td>
<td>Price of Coal ($/ton)</td>
</tr>
<tr>
<td><strong>MandatoryUtilityGreenPowerOp</strong></td>
<td>Equals one when state has Mandatory Utility Green Power Option Policy and zero otherwise</td>
</tr>
<tr>
<td><strong>RenewablesPortfolioStandard</strong></td>
<td>Equals one when state has Renewable Portfolio Standard Policy and zero otherwise</td>
</tr>
<tr>
<td><strong>MandatoryUtilityGreenPowerOpdum</strong></td>
<td>Interaction Variable between <strong>MandatoryUtilityGreenPowerOp</strong> and <strong>Damages</strong></td>
</tr>
<tr>
<td><strong>RenewablesPortfolioStandarddum</strong></td>
<td>Interaction Variable between <strong>RenewablesPortfolioStandard</strong> and <strong>Damages</strong></td>
</tr>
<tr>
<td><strong>CoolingDay</strong></td>
<td>The number of degrees that a day’s average temperature is above 65°F Fahrenheit</td>
</tr>
<tr>
<td><strong>HeatingDays</strong></td>
<td>The number of degrees that a day’s average temperature is below 65°F Fahrenheit</td>
</tr>
</tbody>
</table>

In the next section, I discuss my data.
Data and Descriptive Statistics

To estimate my three models I use data from three sources. The U.S. Department of Energy’s Energy Information Administration (EIA) is the source of two of the major pillars of my data set. The first is state energy production by energy source: coal, petroleum, natural gas and renewable sources. My dependent variable, Renewables, is a continuous variable which consists of the sum in megaWatt hours of hydroelectric, nuclear, geothermal, solar, wind, and wood fuels energy generation. I use data for the years 2001 to 2014. I also use EIA data on other energy sources to include as independent variables. These are coded as coal, oil, and gas. One mWh can power 650 residential homes for one hour.

EIA is also the source of the second major pillar of my dataset. These are coded as Coalprice, Crudeoilprice and Naturalgasprice, which are the annual average crude oil and natural gas prices for the period 2001-2014. These data are available from the EIA at a daily level, which I converted to monthly averages, and then to annual averages. I use these data as independent variables, but as these are potential sources of endogeneity, they are not the primary focus of my regressions. These prices are measured in inflation adjusted 2014 U.S. dollars.

Data for the third pillar of my dataset comes from the Database of State Incentives for Renewables & Efficiency (DSIRE). DSIRE contains data on all state and local renewable and efficiency policy measures. I have removed data on local policies from the dataset in order to focus on programs that affect the state as a whole. A majority of start and end dates were missing from the dataset; so I went through the individual programs to determine the proper start and end dates and to ensure that these were reflected in my data. For all programs that are still active I included the end date as the end of 2014 to coincide with the end of my energy data. For start
dates that I could not find, I used the date that programs were included in the database as the start date, and for end dates that were unattainable I assumed the policy was still active at the end of 2014. I used dummy variables for MandatoryUtilityGreenPowerOp and RenewablesPortfolioStandard, my policy variables of interest.

I used data from the U.S. Commerce Department’s National Oceanic and Atmospheric Administration on billion-dollar disasters due to weather and climate. The Damages independent variable is a continuous measure in billions of inflation adjusted (2014) dollars of the amount of damage specific storms (that generated over $1 billion in damage) during the time period 2001 to 2014.

Data for final variables, Coolingday and Heatingdays, which measure the number of days above and below 65 degrees Fahrenheit, come from NOAA.

Table 2, below, shows descriptive statistics for my variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Observations</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damages ($ billion)</td>
<td>700</td>
<td>8.394</td>
<td>20.748</td>
<td>0</td>
<td>180.3</td>
</tr>
<tr>
<td>Renewables (mWh)</td>
<td>700</td>
<td>8,185,696</td>
<td>1.48e+07</td>
<td>0</td>
<td>9.98e+07</td>
</tr>
<tr>
<td>CrudeOilPrice ($2014)</td>
<td>700</td>
<td>67.16</td>
<td>26.53</td>
<td>25.95</td>
<td>99.57</td>
</tr>
<tr>
<td>NaturalGasPrice ($2014)</td>
<td>700</td>
<td>5.24</td>
<td>1.89</td>
<td>2.75</td>
<td>8.86</td>
</tr>
<tr>
<td>CoalPrice ($2014)</td>
<td>700</td>
<td>27.69</td>
<td>7.61</td>
<td>17.38</td>
<td>41.01</td>
</tr>
<tr>
<td>MandatoryUtilityGreenPowerOp</td>
<td>700</td>
<td>0.04</td>
<td>0.20</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>MandatoryUtilityGreenPowerOpdum</td>
<td>700</td>
<td>0.18</td>
<td>1.69</td>
<td>0</td>
<td>32.7</td>
</tr>
<tr>
<td>RenewablesPortfolioStandard</td>
<td>700</td>
<td>0.76</td>
<td>0.43</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>RenewablesPortfolioStandarddum</td>
<td>700</td>
<td>5.34</td>
<td>13.63</td>
<td>0</td>
<td>155.6</td>
</tr>
<tr>
<td>CoolingDay</td>
<td>675</td>
<td>1,112.18</td>
<td>772.17</td>
<td>0</td>
<td>3,545</td>
</tr>
<tr>
<td>HeatingDays</td>
<td>672</td>
<td>1,973.49</td>
<td>776.31</td>
<td>102</td>
<td>3,898</td>
</tr>
</tbody>
</table>

I next present my results.
Empirical Results

My three models test the collinearity of fossil fuel prices and state level policy to ensure that estimated effects of storm damage on renewable energy production are accurate. Results for these models are reported below in Table 3, Table 4, and Table 5.

In the three equations I used in my analysis, the F-statistics are 11.20, 11.85, and 11.20 respectively, all highly significant, and the adjusted R-squared for the models is 0.9604 for all three. As mentioned in the empirical model section, I expect my independent variable of interest, Damages, to be positive. For my control independent variables, I expect the three price variables to be positive, the two policy variables to be positive, and both the heating and cooling degree days to be positive as well.

Table 3: Model 1 Results.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable Name</th>
<th>Coefficient (Robust Standard Error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damages due to Climate Change</td>
<td>Damages</td>
<td>7,306.38** (3273.528)</td>
</tr>
<tr>
<td>Price of Crude Oil</td>
<td>CrudeOilPrice</td>
<td>96,893.93*** (37,173.91)</td>
</tr>
<tr>
<td>Price of Natural Gas</td>
<td>NaturalGas Price</td>
<td>1,367,0091.00 (940,326.3)</td>
</tr>
<tr>
<td>Price of Coal</td>
<td>CoalPrice</td>
<td>-136,670.4 (137477.8)</td>
</tr>
<tr>
<td>Mandatory Utility Green Power Option</td>
<td>MandatoryUtilityGreenPowerOpdum</td>
<td>243,506.50**** (61,619.16)</td>
</tr>
<tr>
<td>Renewable Portfolio Standard</td>
<td>RenewablesPortfolioStandarddum</td>
<td>-1,668.07 (7,661.04)</td>
</tr>
<tr>
<td>Cooling Degree Days</td>
<td>CoolingDays</td>
<td>-351.22 (1,173.98)</td>
</tr>
<tr>
<td>Heating Degree Days</td>
<td>HeatingDays</td>
<td>2,260.36** (1,074.73)</td>
</tr>
<tr>
<td>Constant</td>
<td>_Cons</td>
<td>-3,228,942 (3,611,566)</td>
</tr>
</tbody>
</table>

F (18, 606): 11.20**** R-squared: 0.9642 Adjusted R-squared: 0.9604
Significant at p<0.10*, p<0.05**, p<0.01***, p<0.0001****
### Table 4: Model 2 Results.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable Name</th>
<th>Coefficient (Robust Standard Error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damages due to Climate Change</td>
<td>Damages</td>
<td>6,674.01* (3,508.94)</td>
</tr>
<tr>
<td>Price of Natural Gas</td>
<td>NaturalGas Price</td>
<td>1,989,038* (1,143,763)</td>
</tr>
<tr>
<td>Price of Coal</td>
<td>CoalPrice</td>
<td>221,708.90**** (47,529.02)</td>
</tr>
<tr>
<td>Mandatory Utility Green Power Option</td>
<td>MandatoryUtilityGreenPowerOpdum</td>
<td>243,028.60**** (61,552.76)</td>
</tr>
<tr>
<td>Cooling Degree Days</td>
<td>CoolingDays</td>
<td>-361.70 (1185.32)</td>
</tr>
<tr>
<td>Heating Degree Days</td>
<td>HeatingDays</td>
<td>2262.19** (1,073.92)</td>
</tr>
<tr>
<td>Constant</td>
<td>_Cons</td>
<td>-9,392,321* (5,229,384)</td>
</tr>
</tbody>
</table>

F (18, 606): 11.85****  R-squared: 0.9642  Adjusted R-squared: 0.9604
Significant at p<0.10*, p<0.05**, p<0.01***, p<0.0001****

### Table 5: Model 3 Results.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable Name</th>
<th>Coefficient (Robust Standard Error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damages due to Climate Change</td>
<td>Damages</td>
<td>7,306.38** (3273.53)</td>
</tr>
<tr>
<td>Price of Natural Gas</td>
<td>NaturalGas Price</td>
<td>1,987,257* (1,143,850)</td>
</tr>
<tr>
<td>Price of Coal</td>
<td>CoalPrice</td>
<td>221,899.80**** (47,637.16)</td>
</tr>
<tr>
<td>Mandatory Utility Green Power Option</td>
<td>MandatoryUtilityGreenPowerOpdum</td>
<td>243,506.50**** (61,619.16)</td>
</tr>
<tr>
<td>Renewable Portfolio Standard</td>
<td>RenewablesPortfolioStandarddum</td>
<td>-1,668.07 (7,661.04)</td>
</tr>
<tr>
<td>Cooling Degree Days</td>
<td>CoolingDays</td>
<td>-351.22 (1,173.98)</td>
</tr>
<tr>
<td>Heating Degree Days</td>
<td>HeatingDays</td>
<td>2,260.36** (1,074.73)</td>
</tr>
<tr>
<td>Constant</td>
<td>_Cons</td>
<td>-9,395,859* (5,233,719)</td>
</tr>
</tbody>
</table>

F (18, 606): 11.20****  R-squared: 0.9642  Adjusted R-squared: 0.9604
Significant at p<0.10*, p<0.05**, p<0.01***, p<0.0001****
In each of my three models I find that the relationship between damage due to climate change and renewable energy is statistically significant at various levels. Model 1 containing all three fossil fuel prices and both renewable energy policies shows that an extra one billion dollars in storm damage lead to an increase in renewable energy production of 7,306 megawatt hours. This is enough to power almost 1.2 million homes for one hour. The impact of damages remains the same in model 3 which removes the price of crude oil. When I also take out the renewable portfolio standards, the impact of damages on renewable energy production decreases, but is still statistically significant. The coefficient for this model indicates that an extra one billion dollars in storm damages lead to an increase in renewable energy production of 6,674 mWh. This would still result in the powering of slightly over 1 million homes for one hour.

My other main variables of interest are the two policy variables, \textit{MandatoryUtilityGreenPowerOpdum} and \textit{RenewablesPortfolioStandarddum}. The results for the Mandatory Utility Green Power Option turn out as expected. The coefficient on this variable is 243,506.50 in model 1, and 243,028.60 and 243,506.50 in models 2 and 3 respectively. These results are all highly statistically significant, and show that, on average, a state that has a Mandatory Utility Green Power Option will be able to power 4,578 more homes per year than a state that doesn’t have a plan in place. However, the coefficient on the Renewables Portfolio Standard policy, though, turns out to not be significant. Therefore, I cannot determine whether this policy has an effect on renewable energy production. By removing the Renewable Portfolio Standard policy in model 2 I tested for collinearity between the two policy options. In model 2 the Mandatory Utility Green Power Option continued to be highly significant with a similar value. Therefore, I conclude that the effect of this this policy is robust.
The coefficients on the fossil fuel prices in the first model were quite surprising. I expected that the coefficients on the prices for all three would be positive and significant. However, only the price of crude oil and natural gas are significant. Coal price has a negative non-significant coefficient which implies that as the price of coal increases the production of renewable energy will decrease. Although this is not a significant finding it implies some sort of collinearity between the three fossil fuel prices. To test for this, I ran model 2, which removed the price of crude oil, and found that not only is there a positive correlation between the price of coal and renewable energy production, but it is also highly significant. For every dollar increase in the price of coal, renewable energy production increases by 221,709 mWh. The effect of the natural gas price on renewable energy production shows that a one dollar price increase will cause renewable energy production to increase by 1,989,038 mWhs. These two significant variables show that renewable energy production is correlated with the prices of fossil fuels, in the direction that would be expected. These results also indicate that non-renewable and renewable sources of energy are substitutes.

The final variables in my analysis are heating and cooling degree days. In all three models, the coefficients on these two variables remain consistent. The coefficient on CoolingDays is not statistically significant, though it and shows that for an increase of one cooling degree day renewable energy production will decrease by approximately 350 mWh. In contrast the coefficient on HeatingDays is significant and shows that for an increase of one heating degree day renewable energy production will increase by just over 2,260 mWhs. This may indicate that renewable energy production is more sensitive to the temperature of a state decreasing than increasing.
In summary, the price of natural gas and coal, a Mandatory Utility Green Power Option, and heating degree days are all positively correlated with renewable energy production. My models show the results I expected, with damages from climate change related storms associated with an increase in renewable energy production. There was collinearity in my first model between my fossil fuel variables. However, after correcting for this, the significance of my damages variable decreased yet still remained significant. In all of the models the coefficients on heatingdays and mandatoryutilitygreenpoweroptiondum were significant, showing that these variables have an impact on the production of renewable energy production. I can also see that damages from climate change related storms have a relationship with renewable energy production when controlling for other significant factors.
Conclusion and Policy Implications

In the United States, climate change is a growing threat and renewable energy is a growing industry. There is also consensus in the literature that the government must address the issue. One way to do this is to promote the use of renewable energy as it releases fewer greenhouse gases than its fossil fuel counterparts.

In my literature review I work to show the link between greenhouse gases and renewable energy, greenhouse gases and climate change, and climate change and natural disasters. By doing this I could study the connection between natural disasters and renewable energy production. I also looked into which state policies were most effective in the literature and a Mandatory Utility Green Power Option and Renewables Portfolio Standards were the most effective. I created a dataset which combined data from the Database of State Incentives for Renewables and Efficiency, the U.S. Energy Information Administration, and the National Oceanic and Atmospheric Administration. I examined this relationship in order to provide research that can be used in determining the best way for governments to promote renewable energy production.

My research explores the relationship between natural disasters which are associated with climate change and renewable energy production. My hypothesis looks at whether states that are at risk to the effects of climate change produce more renewable energy than states that are not at risk to climate change. If there is a connection between natural disasters and renewable energy production then my research can serve as a guide for states that wish to implement policies that promote renewable energy production.

My models predict that an increase in damages associated with climate change has a positive effect on the production of renewable energy at the state level. I control for the policy
variables of renewables portfolio standards and a Mandatory Utility Green Power Option, the production of fossil fuels, and heating and cooling degree days. These models show that there is a relationship between damages related to climate change and renewable energy production at the state level. My models also show that renewables portfolio standards do not have an effect on renewable energy production; however the Mandatory Utility Green Power Option has a strong positive effect on renewable energy production.

These findings suggest that states with higher storm damage should use the Mandatory Utility Green Power Option to increase state-level renewable energy produced. The way this program works is that electric utilities in the state are required to offer green power options to their customers. This will allow customers to choose green power as an option and support the growth of renewable energy (DSIRE).

My models also show that an increase in coal prices has a large effect on renewable energy production. Therefore, one way a state could help to promote renewable energy would be by adopting the politically unpopular carbon tax on fossil fuels. The findings indicate that outside of relying on market forces, a tax is the best way to achieve a price increase.

Following the devastation of Hurricanes Katrina and Rita, the Louisiana Governor’s Office of Homeland Security and Emergency Preparedness and the Federal Emergency Management Agency (FEMA) provided more than $19 billion dollars in relief. This included assistance to the almost one million individuals and families affected as well as funding for mitigation projects. After Superstorm Sandy wrecked parts of the northeast U.S., FEMA provided over $16 billion in disaster relief to New York and New Jersey (FEMA). However, my results suggest that this kind of response may be misguided. Perhaps to entice states to increase
their production of renewable energy the federal government should not provide aide to states that incur damages as a result of climate change. This would add pressure on state governments to raise the necessary funds to provide aide on their own. Moreover, without a carbon tax it is unlikely that a state such as Louisiana would be able to raise the necessary funds to provide relief following a major hurricane. However, Louisiana is a major producer of oil and gas, having produced almost 300 million megawatt hours-worth of oil and natural gas in the last five years. Taxing this production would help the state raise the necessary funds for damage relief as well as to promote the growth of renewable energy. Over time, as Louisiana and other states reduced their greenhouse gas emission and the number and intensity of storms might decrease.

Another option for climate-effected states to raise the necessary disaster relief funds would be to rely on states that continue to produce large amounts of fossil fuels. As discussed in my background section certain regions in the U.S. face harsher effects from climate change than other regions. If a state like California, which is a leader in renewable energy, faces severe drought due to climate change, they should be able to require a state like Wyoming, which is a major fossil fuel producer yet does not face effects of climate change as harsh as those in California, to provide disaster relief funding. A policy like this would also encourage states that do produce significant amounts of fossil fuels energy to rethink their energy production strategy.

The best way for states to address the risks of climate change and to reduce major storm damage over the long term is to implement policies that increase renewable energy. My research indicates that the Mandatory Utility Green Power Option is the most effective statewide policy to increase the production of renewable energy. If states across the country are able to institute
such policies, then the risk of storms related to climate change should decrease and billions of dollars in damages can be saved.
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