EXAMINING THE BENEFITS OF RENEWABLE ENERGY: WIND POWER

by

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Abstract

This report provides a summary of the state of wind energy in the United States, the policy instruments used to encourage renewable energy and the research finding on the benefits of wind energy. It provides insight from a Texas case study, as well as international perspectives. Renewable and non-renewable energy sources are defined and compared. The report discusses the negative environmental impacts of conventional power generation, in contrast to lack of emissions from renewable power. Background information on U.S. energy consumption and climate change are provided. The primary policies used to promote renewable energy, which apply to wind power, are explained. The economic theory behind the relationship of subsidies and externalities is explained, as well as the implications that firm profit-maximization has on market outcomes. This report finds that the benefits derived from wind energy production and the promoting policies outweigh the costs associated with them.

Table of Contents

List of Figures

List of Tables

1. Introduction

Our conventional methods of electricity production are unsustainable. We utilize finite resources to meet our daily energy demands. These finite resources, primarily fossil fuels, also damage our environment. A recent report from the UN's Intergovernmental Panel on Climate Change (IPCC) warns that adverse climate change is already affecting the world, by means of more frequent and intense heat waves, droughts, and floods (Field et al., 2014).

Renewable energy is the key to the conundrum, and wind energy is currently the most efficient technology in terms of cost per unit of power (Johnstone et al., 2010). Wind energy helps society and the environment by reducing the use of non-renewable fuels and offsetting hazardous emissions from conventional power plants. Pollutants such as sulfur oxides (SO_x), nitrogen oxides (NO_x), and carbon dioxide (CO_2) can be significantly reduced when wind-generated electricity replaces conventional, fossil-fueled power plants.

The United States Environmental Protection Agency (EPA) provides a number of facts about these emissions (EPA, 2014). First, sulfur dioxide (SO_2) causes adverse respiratory effects from merely short-term exposure, and, while the emissions are regulated to protect all people, regulation especially protects at risk groups such as children, the elderly, and asthmatics. Of the sulfur dioxide emissions in the United States, 73% are from fossil fuel combustion at power plants (EPA, 2014). Second, nitrogen oxides also cause adverse respiratory effects from short-term exposure, and NO_2 contributes to ground-level ozone. Third, CO_2 substantially contributes to climate change. Additionally, airborne sulfur oxides and nitrogen oxides are known to react with water vapor to create acids, resulting in acid rain (Rosen and Gayer, 2010). Electricity production accounts for 38% of U.S. CO_2 emissions, which is more than automobiles emit, which is 31% of U.S. CO_2 emissions (EPA, 2014). In 2011, CO_2 made up 84% of total greenhouse gas emissions in the United States.

The American Wind Energy Association (AWEA) provides information on wind energy. The costs of wind energy have declined over 90% since the early 1980's (AWEA, 2013). The reasons for this decrease include: larger turbines producing more power at a lower average cost, economies of scale for turbine production, and a greater understanding of dynamic wind patterns (Tillemann, 2013). The Energy Information Administration (EIA), a division of the Department of Energy, ranks wind energy as one of the most affordable technologies for new electricity generation. This affordability is in terms of the "levelized" costs, which are the per-kilowatt-hour costs of construction and operation of the generating plant over its assumed lifespan (EIA, 2013). Included in the levelized costs are factors such as capital costs, fuel costs, fixed and variable operations and maintenance costs, and financing costs. The Annual Energy Outlook (AEO) of 2014 finds that the average levelized cost per MWh of wind is $80, solar (photovoltaic) is $130, and coal and nuclear are each close to $96 (EIA, 2014). In 2012, nearly 42% of new generating capacity installed was from wind energy, making it the largest source of new capacity that year (EIA, 2013). The United States currently has approximately 60,000 megawatts[1] (MW) of wind capacity installed, from 45,000 turbines, providing enough electricity for the equivalent of 15 million American homes.

Wind energy is cost-competitive to conventional power generation, and legislation is in place to help support its development (Cullen, 2011). Wind energy is considered

[1] Electricity is measured in watts, sometimes in kilowatts (1,000 watts) and even megawatts (1,000 kilowatts or 1,000,000 watts). A single watt is quite a small amount of power, with almost 750 watts being equivalent to just one horsepower (EIA, 2013). Electricity generation and household use is measured by kilowatt-hours (kWh), with a kilowatt-hour equaling the energy of 1,000 watts working for one hour. For example, a 60-watt light bulb turned on for 4 hours would use (60x4) 240 watt-hours or 0.24 kilowatt-hours of electrical energy.

cost-competitive because its levelized costs are low enough to be approximately equal to conventional power plant costs. If the recent trend of wind development continues, as seen in figure 1, wind power could become a substantial source of energy production. The net-generation of wind power reached 167 million MWh in 2013, with the total amount of renewable power generation for the year equaling 522 million MWh (Electric Power Monthly, 2014). That same year, the net generation by hydroelectric power was almost 270 million MWh. Photovoltaic solar power had a net generation of 8.3 million MWh, far less than wind or hydroelectric, but at a relatively quick growth rate given that photovoltaic solar generation was under 3.5 million MWh during the previous year.

The main policies used to promote renewable energy technologies in the U.S. are renewable energy certificates (RECs), feed-in tariffs, and tax credits (Johnstone et al., 2010). The impacts these polices have on wind energy will be discussed intermittently throughout this report. To briefly summarize what these policies are, renewable energy certificates are non-tangible proofs-of-purchase for renewably-generated electricity, feed-in tariffs pay energy producers on a per megawatt basis, and tax credits help reduce the costs of investment. As discussed in section 3, these policies can be viewed as a Pigouvian subsidy, where the negative externalities offset are compensated by the sum of the subsidies given. In addition to wind, there are other renewable energy resources: solar, geothermal, ocean, biomass, and waste-to-energy. All of these help work towards a sustainable future, but wind is the most significant. As you can see in figure 2, wind power has presence in a majority of states across the nation.

This report is divided into several sections, with section 2 providing background information on energy and the environment. Section 3 of this report provides a discussion of policy instruments which affect wind power, and presents the pertinent economic theory.

Section 4 is a summary of the literature, followed by the conclusion of this report. The objective of this report is to elaborate on the benefits derived from renewable energies, with a focus on wind power, and discuss government policies which support development and innovation of renewable energy technology.

2. Background on U.S. Energy Markets and Environmental Impacts[2]

Electricity used in a typical American home is most likely generated by a power plant which burns coal, utilizes nuclear reactions, or the force of moving water in a hydroelectric plant. Thus, we define coal, nuclear, and hydro as energy sources. We then categorize two groups of energy sources, renewable and non-renewable: renewable being an energy source which can be replenished, and non-renewable being a source that is finite, and we cannot replace it. As seen in figure 3, only 9 percent of the United States' energy consumption is from renewable sources. The remaining 91 percent is covered by unsustainable fuels which will be depleted, or become cost-prohibitive due to scarcity, in the long run. The non-renewable energy source group includes fossil fuels such as coal, natural gas, and oil. Fossil fuels get their name from how they were formed. Over the course of millions of years, the heat and pressure from within the earth turn the remains of organic life (read: fossils) into things we can use as fuel sources. We use energy sources to generate electricity, which enables most technologies and heavily impacts our daily lives. In 2012, the United States produced 83% of the nation's domestic energy demands. The remaining 17% was primarily imports of petroleum (EIA, 2013).

The production of energy in the United States has significantly changed over time as new forms of energy were developed. Over the last 100 years, coal, natural gas, and petroleum have traded off being dominant energy sources. Surface-mined coal production has grown considerably, providing 25% of energy demand in 1949, and expanding to 68% as of 2011 (EIA, 2013). Better technology and more efficient techniques enabled the highest natural gas production in 2012, over any previous years. As you can see in figure 4, total crude oil

[2] This section is based on information found on the "Energy Explained" section of the EIA website (eia.gov).

production in the United States had been decreasing ever since its peak in 1970, but as of 2010, production has turned upward once again. Domestic crude oil production was higher in 2012 than it had been since 1995. Renewable energy production has seen growth over time as well. Wind turbines in the United States generated around 3% of our total electricity generation in 2012 (EIA, 2013). Although total renewable energy production saw a minor decrease in 2012, due to a reduction in hydropower generation, the production of wind and solar generation have reached record highs.

Energy consumption in the United States is divided into four major sectors. The first is the industrial sector, which contains energy used in manufacturing processes, agriculture, mining and construction. The second sector is transportation, which involves energy used to transport both people and goods by vehicles like cars, buses, trains, trucks, aircraft, and boats. The third sector is residential energy consumption, as used by apartments and homes. The final sector is commercial, with energy consumption for buildings such as offices, stores, hospitals, and restaurants. Energy consumption is widely evaluated using British Thermal Units (Btu), a measure of heat energy, useful for comparing fuels' performance. Referring to figure 5, we see a general upward trend in consumption by all four sectors. A pronounced dip, opposite of the historical trend, can be observed in 2009. This is in part due to the economic recession the United States experienced, and energy consumption fell almost 5%. The decreased energy consumption is observed across all four sectors. Factors such as economic growth, weather, and fuel prices affect consumption in each sector to different degrees.

Energy production from fossil-fuels creates "greenhouse gas" emissions (Rosen and Gayer, 2010). Greenhouse gases, as they are called, allow sunlight to pass through the atmosphere and down to Earth without limitation. Then, some of the sunlight bounces off of the

Earth's surface as infrared radiation, which gets absorbed by greenhouse gases and traps the heat in the atmosphere. There are many compounds which function as greenhouse gases within our atmosphere, some of which are naturally occurring, and others that are a side effect of human activities. Without the naturally occurring greenhouse gases, the average temperature on the Earth would be approximately -2 degrees Fahrenheit, instead of the 57 degrees we currently observe (EIA, 2013). This would be too cold to sustain any life as we know it.

The proportions of several notable greenhouse gases have risen by roughly 40% over the last 150 years, when large-scale industrialization began (EIA, 2013). Concentrations of CO_2 are naturally regulated via processes like photosynthesis, which we refer to in sum, as the "carbon cycle." Despite this natural regulation, it is estimated that over 4 billion metric tons of CO_2 are added each year to our atmosphere (EIA, 2013). This imbalance of emissions, brought about by human activities, causes the atmospheric concentration of greenhouse gases to continually increase. The scientific community affirms with near-certainty, that this increase of greenhouse gas concentrations leads to a warmer planet. With warmer temperatures comes changes in sea level, precipitation patterns, and the severity of storms. This is what we have come to call "climate change."

Intergovernmental studies find that the Earth's average temperature has increased by approximately 1.1 to 1.6 degrees Fahrenheit over the last century (EIA, 2013). While natural causes could engender climate variance over time, it is "very likely" that human activity, by way of greenhouse gas emissions, has been an influential component. In the United States, greenhouse gas emissions come mainly from the fossil fuels that are burned for energy. Energy demand is highly correlated to economic growth, and the short-run variance of this growth stems from weather patterns changing people's heating and cooling needs. Fuel used for electricity generation changes from time to time, which changes our energy use (EIA, 2013).

As seen in figure 6, coal is a major fuel source for electricity production, generating 41% of electricity in the United States in 2012 (EIA, 2013). That 41% produced is responsible for 74% of CO_2 emissions resulting from the generation of electricity. So coal is both a major energy provider, as well as a majority source of CO_2 emissions. Given these high levels of emissions, coal-fired power plants are probably the first candidate to be replaced for cleaner electricity generation. This is where renewable energy plays another important role, besides its basic function to provide sustainable electricity.

When renewable sources are utilized, the electricity demand covered by fossil fuels is reduced. Thus, given that renewable energies do not directly emit greenhouse gases, as renewable use increases, fossil fuel use will decrease and subsequently so will emissions. Renewable energy is not a new idea, where over 150 years ago, wood (a form of biomass and a renewable source) supplied up to 90% of the United States' energy needs. As the use of fossil fuels expanded, we grew less reliant on wood as a source of our energy. Now, as environmental concerns become increasingly prominent, we again seek out renewable sources to cover our growing energy needs.

While renewable energy sources have some clear advantages over non-renewable sources, why are we not using more of them? Historically, renewable energy has been more expensive to produce and use than its fossil fuel counterparts (EIA, 2013). Renewable resources are often generated in rural areas, requiring costly power lines to be installed so the electricity produced can flow into cities where it is needed. Renewable resources can also be hampered by uncontrollable factors, such as a cloudy and windless day in the middle of a drought, would mean low solar, wind, and hydropower energy production. However, renewable energy production has increased in recent years due to a number of factors. Higher prices for fossil fuels, plus federal and state incentives for renewable energy, have refilled the sails of renewable energy development (EIA, 2013). The American Recovery and Reinvestment Act of 2009 provided an estimated $10.9 billion for incentivizing alternative/renewable energies and energy efficiency (recovery.gov, 2012). Even though renewable energy is on the rise, the United States Energy Information Administration forecasts that we will still depend on non-renewable fuels to cover most of our energy demands 30 years from now (EIA, 2013).

The renewable energy source focused on in this report is wind energy. Wind turbines use blades to catch the wind's kinetic energy in a similar fashion to an airplane's wing. The wind is caught and creates motion in the form of rotation for wind turbines, or lift for airplanes. The rotating blades of a wind turbine are connected to an electric generator to produce electricity. Electricity generation from wind has boomed in the United States recently. As you can see in figure 1, the capacity has been growing at relatively large rates per year since the around the year 2000. There are fluctuations in capacity growth for wind energy, and these fluctuations are tied to the expiring and renewing of policies which promote their production. These policies will be discussed in a later section.

The benefits to wind-generated electricity are multi-faceted. As mentioned earlier, wind power offsets demand at conventional power plants, reducing hazardous emissions. Wind power is becoming one of the most cost-competitive sources of electricity generation, making it a great candidate for new capacity installation versus other types of power plants (AWEA, 2013). Currently, most other renewable sources of electricity are relatively expensive, aside from geothermal which also has relatively low costs. However, geothermal is dependent on resources not available to all countries (Johnstone et al., 2010). The development of wind farms boosts local economies and provides jobs during the construction and throughout the operating lifespan of the wind farm (Slattery et al., 2011). If you can replace a non-renewable, conventional power plant with a wind farm, then the local air quality and overall quality of life for residents will improve due to the lack of hazardous emissions. In sum, the rapid technological advancements to wind power in recent years and its falling costs of production have made wind power a competitive, renewable source of electricity. Transitioning to renewable energies will help our country achieve a lower carbon footprint.

3. Wind Power Subsidies and Economic Theory

There are three primary types of policy which affect wind power and that are addressed by the literature. One of the common subsidies available for wind power in the United States is the Feed-in Tariff, or FIT (Cullen, 2011). The feed-in tariff is a subsidy to wind farms for every megawatt-hour they generate, giving them greater incentive to increase their energy output. The amount that is paid varies by technology, with lower-cost energy technologies receiving a smaller subsidy per megawatt-hour than higher-cost technologies. The literature suggests that feed-in tariffs are the most effective policy for increasing renewable power production, in general, when compared to other currently active policies (Johnstone et al., 2010). Feed-in tariffs reduce the risk of investment in renewable technologies by guaranteeing income for each unit of energy produced. Feed-in tariffs are found at the state and federal level.

Another type of policy is where the government requires electric companies to provide a target amount of electricity generated from renewable sources, and they may decide how to achieve this target (Johnstone et al., 2010). Renewable energy certificates (RECs) are the mechanism which enable electricity providers to purchase units of renewably produced electricity, in order to achieve the mandated target. The price of renewable energy certificates varies by the generation source. Lower-cost technologies, like wind power, will be represented by lower-priced certificates. By giving electric companies the choice between technologies, low-cost renewable sources become more attractive compared to high-cost sources, given that firms are cost-minimizers. Renewable energy certificates are not bound by states, so a utility company with a mandate for renewable energy production may fulfill the requirements by purchasing certificates from renewable power sources located anywhere in the United States. Renewable energy certificates are a federal policy.

The third major policy type is tax credits. Tax credits come in various forms, and in general, they promote new investments in wind power. For instance, a tax credit may help reduce the direct costs of wind farm construction. As noted in Cullen (2011), the marginal costs of wind production are very low and the tax credit can offset the large sunk costs of a turbine. Another tax credit may prevent property values, and thus property taxes, from skyrocketing due to new wind farm development (Windustry, 2006). This makes new wind farm investments more appealing to both the land owners and the wind farm developers. The tax credits available are different at the federal and state levels of policy.

In recent years, the United States has let some policies which promote renewable energy developments expire, and then they have retroactively renewed the policies within a year of expiration. One such policy, the Production Tax Credit (PTC), which is a type of feed-in tariff, has been allowed to expire on several occasions since it began in 1992 (AWEA, 2013). In figure 1, the correlation between drops in production when policies expired, and subsequent jumps when the policies were renewed the next year, can be observed by the annual amount of wind power installations. This inconsistency increases the risk of investments, and has hurt wind power development in the years it occurred (AWEA, 2013). At the time of writing this report, more policies/subsidies which support renewable energy have recently expired and not been renewed. Although a bill to once again extend these policies has been approved as of April 3rd, and it now awaits a vote from the Senate (Francis, 2014). The inconsistency is unhealthy for growth (Rosen and Gayer, 2010), and in a later section, the effects of Germany's inconsistent policy decisions are discussed.

The notion of externalities is prevalent throughout the literature and analysis of wind power. Positive externalities are additional benefits derived from the production of a good or service, in this case wind power, which are not factored into the equilibrium price. Public policy can correct market failures from externalities, whether positive or negative. The policies discussed above serve as Pigouvian subsidies and lead market participants to internalize the external benefits derived from wind power development. Pigouvian subsidies "correct" for the presence of positive externalities: the sum of public and private marginal benefits exceed the private marginal costs, and as a result, the market produces too few units of the good to be provided at a socially efficient level (Rosen and Gayer, 2010). In the case of wind power generation, the positive externality is the reduction of fossil fuels burned at conventional power plants, which results in fewer hazardous emissions. Economic theory states that economic efficiency requires a level of production/allocation of resources where social marginal benefit equals social marginal cost. Pigouvian subsidies can move a market to allocate resources such that market efficiency is achieved (Rosen and Gayer, 2010).

4. Summary of Research Papers

This section summarizes the finding of six research papers covering different aspects of renewable energy adoption. The papers were chosen based on their topics being explicitly about wind power, their relevance to the U.S. and international perspectives, and being relatively recent studies. Three of the papers focus on the experience of the state of Texas, which has been a leader in the adoption of wind energy in the United States. These papers find sizeable positive benefits of wind power adoption. The other three papers take an international perspective on wind power development and government policies. The conclusion from these papers is that wind farms induce positive benefits and policy can be influential for development.

Cullen (2011)

Cullen (2011) examines federal subsidies to wind energy production and how that production offsets emissions from non-renewable power plants. He empirically analyzes data from Texas to put an approximate price on the benefits of wind-generated electricity. The primary data for the analysis comes from the Electric Reliability Council of Texas (ERCOT), the EPA's Emissions & Generation Resource Integrated Database (eGRID), the American Wind Energy Association (AWEA) factsheets, and from the Energy Information Administration (EIA) reports. By using the amount of pollutant emissions a conventional power plant emits for the generation of one unit of electricity, he finds how much pollution can be prevented per unit of wind-generated electricity. With prices from the current system of cap-and-trade regulation, he can estimate the social benefit from the pollution that is offset by wind turbines.

Cullen focuses on the grid managed by Electricity Reliability Council of Texas, which serves most of the state of Texas. The author has a few important reasons for choosing to study this particular grid. One reason is that wind capacity accounts for a notable portion of their electricity generation capacity, with up to 10 percent of electricity consumed at any point in time being produced by wind turbines. Table 1 shows a dissection of Texas electricity generation sources from 2005-2007. Another reason that makes this Texas grid prime for study is that it is mostly isolated from other electrical grids within the United States. Less than one percent of daily generation is transferred outside of Texas, so analysis can be restricted to Texas and not involve the national power grid. The final key factor for selecting Texas is that they produced the greatest amount of wind power in the U.S. during the time period studied. In figure 2, you can see the differences in generation capacity between states.

The author reports that the marginal costs of wind turbines are very low and on a per unit production basis they are almost nonexistent. Most of the costs are from initial capital investment, which is similar to their non-renewable counterpart power plants, except those power plants also have much higher operating costs. The low marginal costs of wind power incentivize the wind farm operators to produce as much electricity as possible. Subsidies are earned for each MWh of output, again promoting maximum electricity production. Once federal and state output subsidies are included, the marginal cost of wind power becomes negative. Hypothetically speaking, a wind farm could remain profitable from its production of electricity, even if the wholesale price of electricity went below zero.

The author thoroughly explains the design of the analysis, and acknowledges some unknown variables that could modify the quantitative conclusions, but the qualitative conclusions remain unaffected. An example scenario is when wind power is on line, it is unknown whether coal or natural gas power plants will cut back production, which affects the costs and types of emissions that are offset. Additionally, knowing that coal plants cause the greatest amount of pollution from operation, this could mean that wind power offsets a larger volume of emissions than might have been expected if coal plants are shut down first. On average, each MWh of electricity generated from the wind turbines will offset a pound of NO_x, roughly 3 pounds of SO_2, and almost 1500 pounds of CO_2. Using these quantities and estimated damage costs of the different pollutants, Cullen can determine what the values of subsidies should be to equal the pollution costs that are offset. In other words, he seeks to calculate the Pigouvian subsidy that would give an efficient market outcome. The author uses permit prices for regulated pollutants (SO_2 and NO_x), combined with estimates for the social cost of unregulated pollutants (CO_2), to establish the costs of pollution. The estimated social cost of CO_2 is the monetized damages associated with a marginal increase in CO_2 emissions, to factors such as net agricultural productivity, human health, and property damages from increased flood risk (United States, 2010). This analysis delivers an estimated value of $5-$34 per MWh generated by wind power for the pollution costs that are offset. The range of this value is due to the fact that offsetting an emissions-heavy power plant, such as coal, would yield a higher social benefit than a lower-emission plant. Texas has several subsidies in place that actually fall within this optimal range. Texas wind energy producers earn a total of approximately $30 per MWh from all the subsidies currently in effect.

In conclusion, the author notes that the quantity of pollutants offset by wind power is dependent on which generators/power plants cut back production when wind power is pumped onto the grid. It is evident though, when comparing the reasonable pollutant valuations to the subsidies which promote wind power investment, that the net benefits for reduced emissions are positive. He acknowledges that the analysis only explains the short-run impacts on emissions, since the results reflect short-run substitution patterns between wind power and conventional power plants. However, this information still provides insight for renewable energy and emissions policies. The analysis confirms there are indeed significant benefits to the environment which exceed the costs of additional investments into renewable power facilities.

Slattery et al. (2011)

Slattery et al. (2011) examines the economic impacts of wind power development in four counties in west Texas. They estimate the impacts on a local level (within a 100-mile radius of the wind farms) and at the state level. The question they ask is what are the effects from investments in wind farms on the state and local communities in which they are built? They utilize the National Renewable Energy Laboratory's (NREL's) Jobs and Economic Development Impacts (JEDI) model for their estimations. This is a regional planning model, as discussed below. They differentiate the economic impacts during the wind turbine construction phase from the economic impacts during the operating and maintenance phase. The construction period of the wind farms they are studying took four years, from 2005 to 2008, and the assumed operating life cycle of the farms is 20 years. You can see the growth of wind generation occurring during most of the construction period, in table 1.

The authors note the importance of analysis on the local level, as many of the impacts observed from wind energy projects are largely local. Local impacts such as those on economic development, the aesthetics of turbines, any noise caused by the turbines, and possible wildlife displacement effects are mentioned in the study. The authors raise the point that, although public and political support for wind energy is high, it is the local communities which are close to a new wind farm site who are concerned. The local communities can gain more from wind farm construction and operation if local businesses participate. Some construction or repair equipment could be supplied locally, and the workers will need food and potentially a place to stay. Workers will most likely be brought from outside the local area for the project, with local workers assisting. There is a chance that some of them move in to the area, especially if they are part of the post-construction, operating and maintaining crew. The local service industry, such as hotels and restaurants, often see an increase in business activity as a product of the onsite work on wind farms.

The authors maintain that the JEDI model's appropriateness is validated by its former use by the US Department of Energy, the US Department of Agriculture, and the National Renewable Energy Laboratory. These institutes, as well as a number of universities, have used the JEDI model for the analysis of the economic impacts that are due to wind farms. The model assumes input-output multipliers and consumption patterns, and can be applied at the county, state, regional, or national level. Within the four-year construction phase, the number of full time equivalent jobs supported is estimated to be in excess of 4,000. The state-wide impacts of these jobs have resulted in an estimated $57 million in earnings, as well as $160 million in economic output per year of the construction period. Between the wind farm sites focused on in the study, there are 63 permanent annual jobs supported from the operating and maintaining phase of this study, which is approximately 20 years. In sum, the lifetime economic activity from the wind farms studied is projected to be almost $2 billion. This means greater than $1.3 million generated per MW of installed wind power capacity.

The authors conclude that, locally, these wind farm projects supported an estimated 900 full time equivalent construction jobs within a 100-mile radius of the project sites. For the duration of the operations and maintenance period, these local jobs resulted in almost $9 million in wages per year, as well as over $30 million per year in economic output. Again assuming the four-year construction and 20-year operating life of the farms, $0.52 million of local economic activity was generated per MW of installed capacity. The authors write that Texas is poised to see additional impacts from additional wind development, and it is likely that other states and regions can experience similar effects.

Kahn (2013)

Kahn (2013) examines changes to various quality of life measures in communities with new wind farms. These measures include public school quality, local air quality, and local fiscal benefits. The paper also seeks to determine the causes for these changes and rationalize them. Population information is taken from the 2000 Census of Population and Housing data, and 2010 data which was purchased from the Aristotle Company. Data on the locations of the wind farms comes from the Federal Aviation Administration (FAA). Data on school performance is from the Children at Risk association. The Texas Association of Counties with data supplied by the Texas Comptroller of Public Accounts covers data on property taxes rates at the county level. For pollution, emissions, and power plant data, the author uses national data from the 2007 EGRID data base, which is created by the United States EPA. The case study covers communities located in the western part of Texas. The paper also compares quality of life measures in wind farm communities versus communities surrounding a power plant which burns fossil fuels. Texas has been a leading state for installing wind turbines, and as of 2011, six out of the ten largest wind farms within the United States are in Texas. The Texas counties of Coke, Nolan, Sterling, and Taylor saw the largest buildup of wind farms. These are the counties that were studied and compared.

The socio-economic effects on these counties are compared to Texas as a whole. Data for the years 1996-2010 is analyzed. The private cost/benefit decision of allowing a wind turbine to be built does not include all those who will be affected by it. Even in rural communities where neighbors are far apart, there will be spillover effects from a new turbine installation.

Neighbors in the community could benefit from new wind turbines because of local tax revenue generated from the sale of the land. That could then, for example, be used to improve local schools. However, a new wind turbine could impose negative externalities, such as noise and appearance, for some members of the community.

The perceived negative impacts of wind farms could potentially be greater if more people lived close to them. The author finds that 50% of registered voters in the counties sampled live within ten miles of the closest wind turbine, and within 5.7 miles of Abilene, the closest city. Only 1% of people in the area studied live within one mile of the closest wind turbine. This study deduces that the wind turbines have not negatively affected the quality of life in the area, or any negative effects are miniscule. It arrives at this assertion from the observation of the quantity of college graduates living in the area before and after the installation of the turbines. College graduates are assumed to earn higher income, and because of this they are able live in an area with a high quality of living. The findings suggest that these people are not avoiding the turbine areas, thus leading to the conclusion that turbines cause minimal negative impacts.

The study finds that the increase in expenditure per student and the decreased student-to-teacher ratio indicate there has been an improvement over time to the schools within the wind farm communities. The wind farm counties' relatively high tax revenue per pupil went into the state and then part of it went into the local schools. Thus the wind farms have been indirectly influential on the local schools and have contributed to an increase in the local quality of life, with no discernible quality of life damage.

Johnstone et al. (2010)

Johnstone et al. (2010) examines the by-products of environmental policies on technological innovation, in specific regard to renewable energy, across multiple countries. It is expected that these policies will stimulate renewable energy production, though to date (of their study) there has not been empirical testing on the relative effectiveness of these policies. This is what the authors seek to discover. They use patent data on a panel of 25 countries over the period 1978-2003 to conduct the analysis. At the time, renewable energy sources are growing, but not as fast as one might expect. Without subsidies, production costs remain higher than for substitute fossil fuels and there are various policies which governments use to promote renewable energy production, such as tradable renewable energy certificates, feed-in tariffs, and tax credits, as discussed in section 3 of this report.

The cross-country focus of this study enables the authors to observe a wide range of policy types. Between the range of countries, which include Germany, Denmark, and Spain, and the various sources for renewable energy (wind, solar, geothermal, ocean, biomass, and waste-to-energy), the authors can evaluate the effectiveness of diverse policy types on each technology. An example of this is solar power. Solar power has higher costs compared to wind power, so it will require different policies for effective promotion. With different cost structures and other variables that change between types of renewable energy production, this study can examine which types of policies work best for promoting specific renewable energy sources. This insight will assist policymakers in steering legislation to drive innovation for specific technologies.

The authors report that the results of their regression analysis are robust. The explanatory data shows brisk growth in patent activity related to wind power, most notably since the mid-1990s. There has been similar relatively high growth in ocean energy patenting, though from a very small base. They observe continued growth in innovation with respect to solar power. However, they find that there has not been much increase in innovation levels relating to geothermal, biomass, or waste-to-energy processes since the 1970s. The signing of the Kyoto

Protocol marks a positive and significant change in patent activity for all types of renewable energy sources. Public expenditures on research and development have consistent positive and significant effects on innovations for wind and solar. For certain iterations of their model, public expenditures on R&D positively affect geothermal and ocean sources as well.

Continuing with results from their regression analysis, they find that feed-in tariffs can enable even high-cost technologies such as solar to be competitive. Since feed-in tariffs are adjusted by generation type, where low-cost generators will get less compensation per unit of energy than a high-cost generator. The data show that feed-in tariffs do not encourage additional innovation for cost-competitive technologies like wind power, which have a low marginal cost of operation.

The authors examine renewable energy certificate (REC) policies. As discussed in section 3, firms purchasing renewable energy certificates will seek to minimize their costs, thus seeking the lowest-cost technology available. Targets for renewable energy certificates show a significant and positive effect on wind power innovation, but no significant effects on solar power. This outcome is expected due to the relationship between the different costs of producing the energy and the assumption that firms strive for cost-minimization. A note, due to the nature of electricity production and usage, once electricity is generated and flows into the grid it is indistinguishable from other electricity. Therefore, a renewable energy certificate is simply supporting that renewable generation, without directly purchasing the "actual" electricity from the generator itself.

In contrast to R&D subsidies and RECs, the authors find that voluntary programs and tax measures such as targeted tax credits have no statistically significant effect on wind innovation. In conclusion, public policy can have a significant effect on renewable energy innovations.

Additionally, as shown by the effects of the Kyoto Protocol signing, future policy expectations can be influential.

Del Rio et al. (2010)

Del Rio et al. (2010) examines the benefits of upgrading the capacity of wind farms. Using examples from Spain and Denmark, they qualitatively analyze instruments and design options for supporting wind farm repowering. Repowering is the process of swapping out existing wind turbines with new turbines to generate more electricity. This can be done by either installing a larger maximum potential capacity turbine or a turbine that is more efficient. The repowering of a wind farm often results in a smaller number of turbines, but the farm generates greater electrical output than before. The authors report that a prime example of this is Denmark, where between 2001 and 2003, almost 1500 turbines that generated a sum of 122 MW were replaced by less than 300 new turbines, yet they could produce over two and half times more total electricity than before. Alternatively, one-fifth as many turbines have the ability to generate greater than 250% of the previous total electrical capacity.

The authors note that incentives to repower must be used with regards to both existing projects that may continue to operate and investments in new wind capacity. There are several factors to be considered with respect to this. One consideration is that higher-capacity modern turbines can make better use of the available wind energy, and the locations of old turbines have already been evaluated as areas with a good wind resource. More points to consider are the lower investment costs of repowering as compared to new wind farm projects, or the availability of a second-hand turbine market to sell the old equipment in. The selling of second-hand turbines can aid in the introduction of wind-power technology to countries that previously had none. Another factor for consideration of repowering is the operating and maintaining costs of old turbines compared to new ones. Older turbines may be prone to more frequent maintenance and thus more downtime, though citing the Spanish Wind Energy Association, the authors state that maintenance costs of new and old turbines are similar, primarily due to the fact that old turbines have fewer electronic components, and therefore less complex and costly to repair. The final consideration detailed covers the risk of the investment, where repowering involves less risk than a new wind farm project because the land is already utilized and thus there is already infrastructure for wind power generation.

Though the benefits to repowering are vast, barriers do exist to repowering. If an existing wind turbine has not reached the end of its useful life, farm owners have far less incentive to invest in repowering when they still receive cash flows from the old investments. The repowering of a wind farm might require grid/infrastructure upgrades depending on the increase in capacity of the wind farm. There could be other quality wind sites available, or logistic issues with the transportation of the newer, larger turbines that may hinder repowering efforts. The temporary cut in the revenue stream from the dismantling and upgrading could be problematic, and lastly there may be new licenses or permits required that delay construction.

There are many potential socioeconomic and environmental benefits of repowering discussed by the authors. Repowering leads to more efficient land usage, and even a noise level reduction due to the smaller quantity of larger wind turbines which rotate slower. The slower and fewer turbines also help decrease avian death from being struck by the spinning blades. Newer turbines will provide better power quality allowing better integration of the wind energy to the electrical grid. With repowering also comes technological advancements and the spread of wind energy knowledge. Additionally, construction jobs will be created during the repowering process.

To ensure that policy instruments support repowering, they should be compared to how these same policies support new wind farm construction. The authors briefly discuss the effects of instruments currently used which support repowering: for example the feed-in tariff system, which they find brings mixed results for promoting repowering. Although Denmark has done a significant amount of repowering, Spain has had "very modest" progress in repowering, and yet both countries have feed-in tariff programs. Another instrument discussed is production tax credits, and they note that repowering could be promoted explicitly with these production tax credits if repowering projects are given a larger credit. They consider how subsidies to investment could promote repowering by gearing them towards new and more efficient technology. The authors conclude that each instrument has benefits and detriments in relation to their effectiveness towards promoting wind farm repowering. They note that the interactions and combinations of instruments that support repowering should be analyzed in future research.

Stegen and Seel (2013)

This paper examines the strides made by and success of Germany in increasing its reliance on renewable energy sources. The authors report that the German government has established multiple goals for Germany's energy and environmental future. They seek to reduce greenhouse gas emissions 40 percent by the year 2020, compared to 1990 levels. As the years proceed, they will require lower and lower greenhouse gas emission targets. They set a target for a national energy consumption reduction of 20 percent by 2020. Again, incremental goals are set for future time periods. Goals have also been set for renewable energies to become the primary sources of electricity, being 35 percent of German total energy production by 2020, incrementally until 2050, where their furthest future goal is 80 percent. Germany currently produces 22 percent of their electricity from renewable energies. They also produce 16 percent of their energy from nuclear power, and after the Fukushima disaster, they seek to rapidly eliminate their use of nuclear power plants. In the absence of nuclear power, Germany will be left with primarily coal and natural gas plants to bridge the gap during their transition to renewable energies.

To understand industry perspectives, the authors survey several major players in Germany's wind energy production. Five of eight companies asked responded to the survey, each helping compile a general outlook for the future. The five companies make up over 80 percent of the German market for wind power. These companies were asked questions relating to feasibility, goals, policy implications, challenges, and more. Most of the questions on the survey asked the companies to respond based on a scale, essentially a 1 to 7, of their agreement/disagreement to a set of statements. On a question that asked the companies to scale how realistic they thought the goals of replacing current conventional electricity sources with renewable energies were, the results were mixed. Two of them rated it as "completely unrealistic", another was neutral, and the other two responded optimistically with "seemingly realistic." When weighting these responses with the market share of the companies, the response was divided was almost exactly even between achievable and not achievable.

As of 2012, Germany's wind energy capacity from both offshore and onshore is almost four times greater than in the early 2000s, totally at 31,156 Megawatts. Within the current energy transition agenda, wind energy will take the most crucial role in capacity expansion, with photovoltaic (solar) following in second. The survey also asked how achievable the goals for wind energy production in 2020 and the goal of covering half of Germany's electricity by 2050. The companies unanimously rated positively, from somewhat positive to "completely realistic", the highest available rating. So for these production goals, the companies were more optimistic than they were about the government's general targets for renewable energies supplying Germany's electricity.

The German energy transition plans are having some struggles with their legislation and implementation. The government is providing monetary incentives for wind and other renewable energies, but they are restricting the capacity expansion of them. The German government is restricting the growth to keep costs down, as rapid expansion would drastically increase electricity, infrastructure, and other costs, at least in the short run. Another issue that arises for the wind industry in Germany, as it does in other countries, is the public opposition and protests of wind turbines. Commonly referred to as a NIMBY, or "not in my backyard" response, where people oppose construction for various reasons including health, aesthetic, or property value concerns. The surveyed companies generally believe, as you would predict, that these NIMBY protests can be problematic.

Another issue is with the electrical distribution infrastructure, specifically in regard to grid expansion. All renewable energy production sites must be integrated with the electrical grid. This will require "...modernization - specifically, smart grids and smart meters to synchronize supply and demand - and decentralization." Grid expansion is viewed as a highly important prerequisite for renewable energies to impact electricity production. So far, Germany has had trouble with the speed at which they are expanding their electrical grids. Four out of five of the surveyed companies stated that delayed grid integration is the biggest hurdle for onshore wind energy.

The authors conclude with a brief analysis of the contradictions within the German government's approach to energy. Germany does not have a designated agency for energy issues. Programs and initiatives are spread across several departments and institutions. The promotion of renewable energies in Germany suffers from what the authors call "push-pullback", where the government simultaneously incentivizes and limits growth, sending mixed messages to renewable energy developers. This is something that German policy-makers must balance, in order to reign in prices and still incentivize production. The paper ends on the notion that other countries can learn from the mixed-signals issue, and that despite setbacks, Germany's energy transition is regarded as successful.

5. Conclusion

Wind-generated electricity has the lowest levelized cost and highest recent capacity growth of all renewable energy sources. With more wind power capacity installed the country becomes less dependent on fossil fuels, thus helping reduce the impact on global climate change. This report provides a summary of the state of wind energy in the United States, the policy instruments used to encourage renewable energy and the research finding on the benefits of wind energy. It provides insight from a Texas case study, as well as international perspectives.

Wind-generated electricity, as Cullen found, offsets hazardous emissions from conventional power plants and the EIA ranks it as one of the most affordable technologies for new generation. Once set up, wind farms have low marginal costs allowing them to be competitive to conventional power plants. Wind energy is an important piece of the world's portfolio of sustainable power sources. As seen from the literature, wind power provides more benefits to society than simply reduced fossil fuel consumption. Kahn concluded that local quality of life is improved when new wind turbines are installed. Slattery et al. found that long-term jobs are created for operations and maintenance crews for the wind farms. Local school systems derive benefits from the additional state revenues brought in by wind farms. Private landowners receive income from turbine installations on their property. From Stegen and Seel, Germany has shown the important role that public policy plays in renewable energy development. Overall, these papers conclude that the various benefits of wind farms exceed the costs and subsidies associated with them. The economic and sustainability benefits of wind-generated power call for greater development and policy intervention.

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Figure 1: Annual Wind Capacity Installations

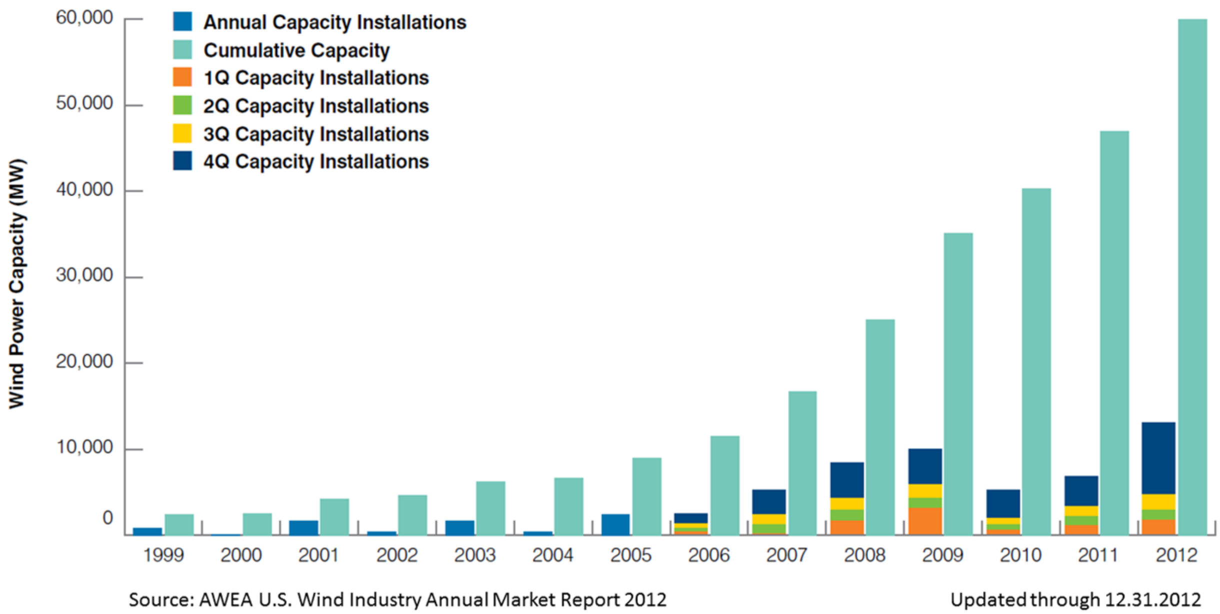


Figure 2: U.S. Wind Power Capacity Installations by State

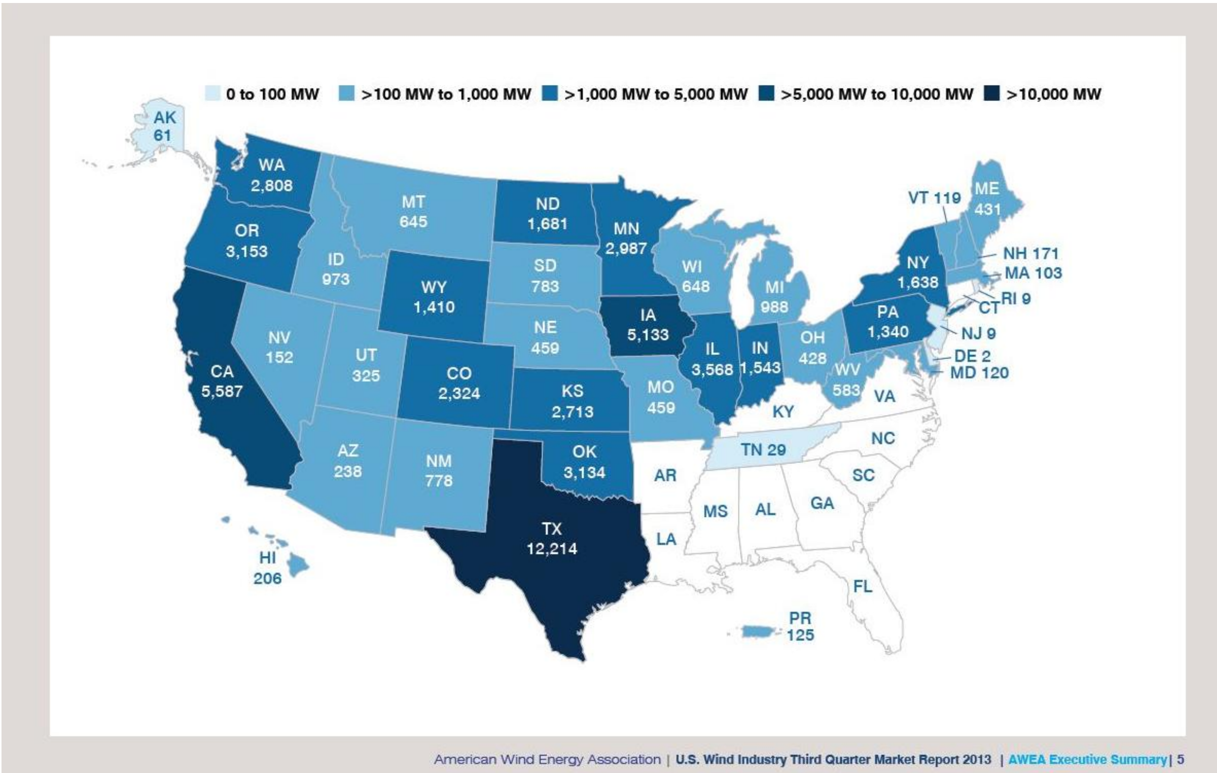
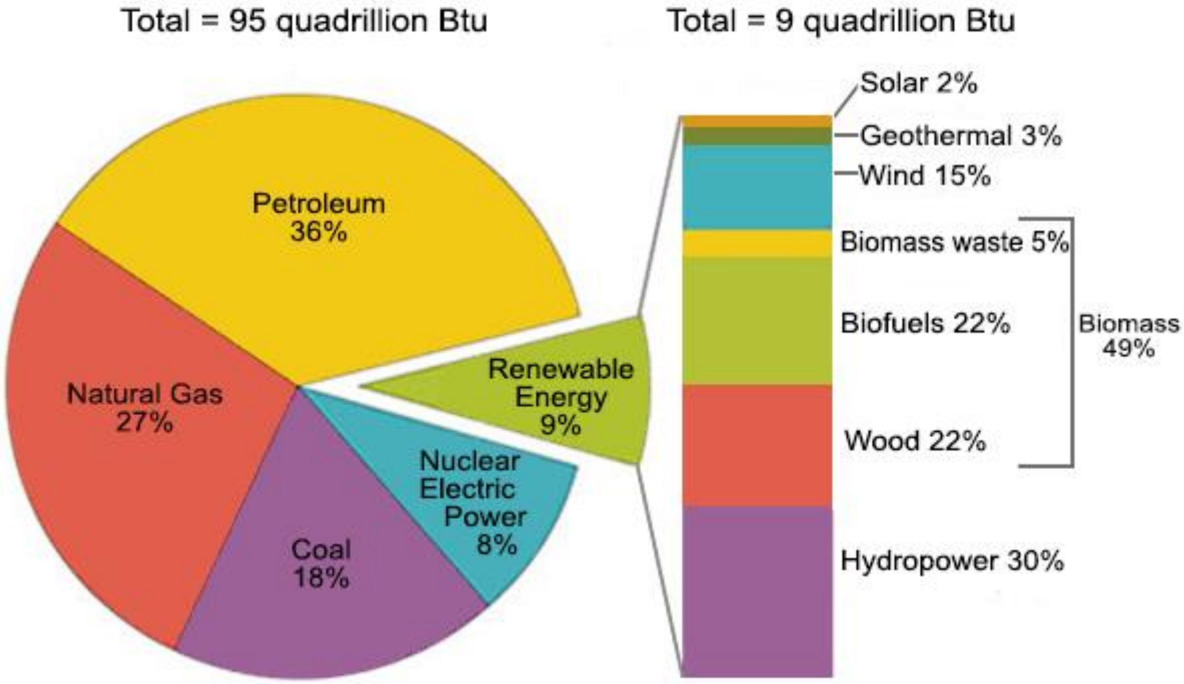
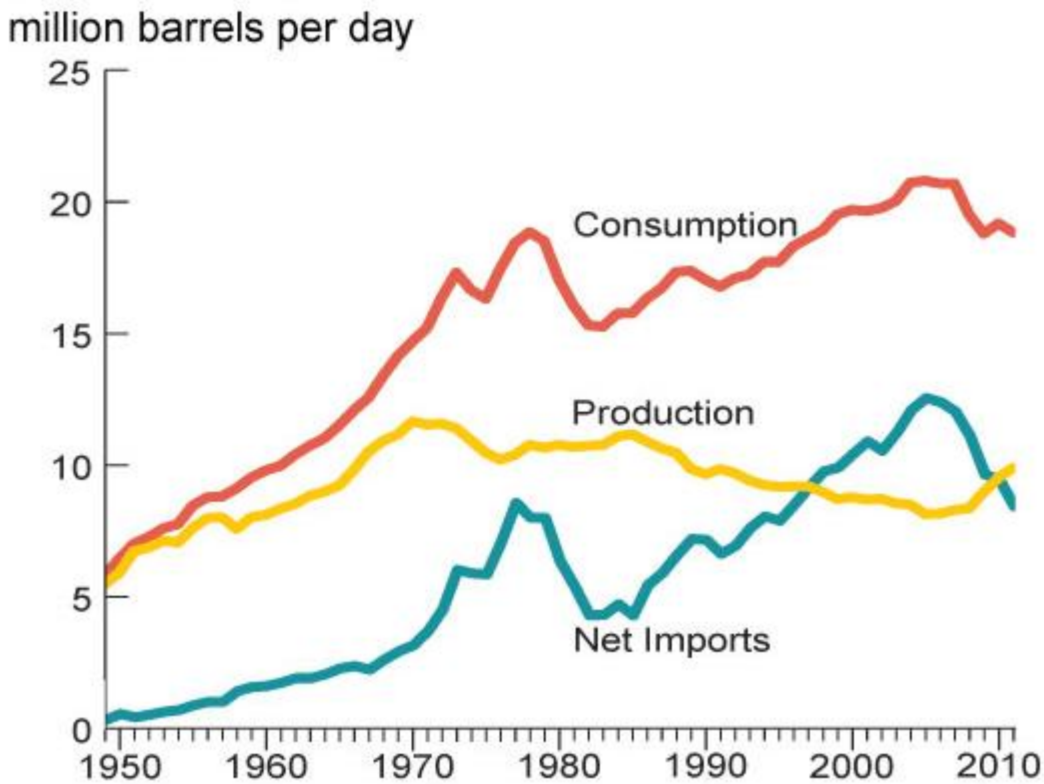


Figure 3: U.S. Energy Consumption by Energy Source, 2012



Note: Sum of components may not equal 100% due to independent rounding.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1 (April 2013), preliminary 2012 data.

Figure 4: U.S. Petroleum Consumption, Production, and Imports (1949-2011)



Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 3.1 (April 2012), preliminary data, and *Annual Energy Review*, Table 5.1a (October 2011).

Figure 5: Energy Consumption by Sector (1949-2012)

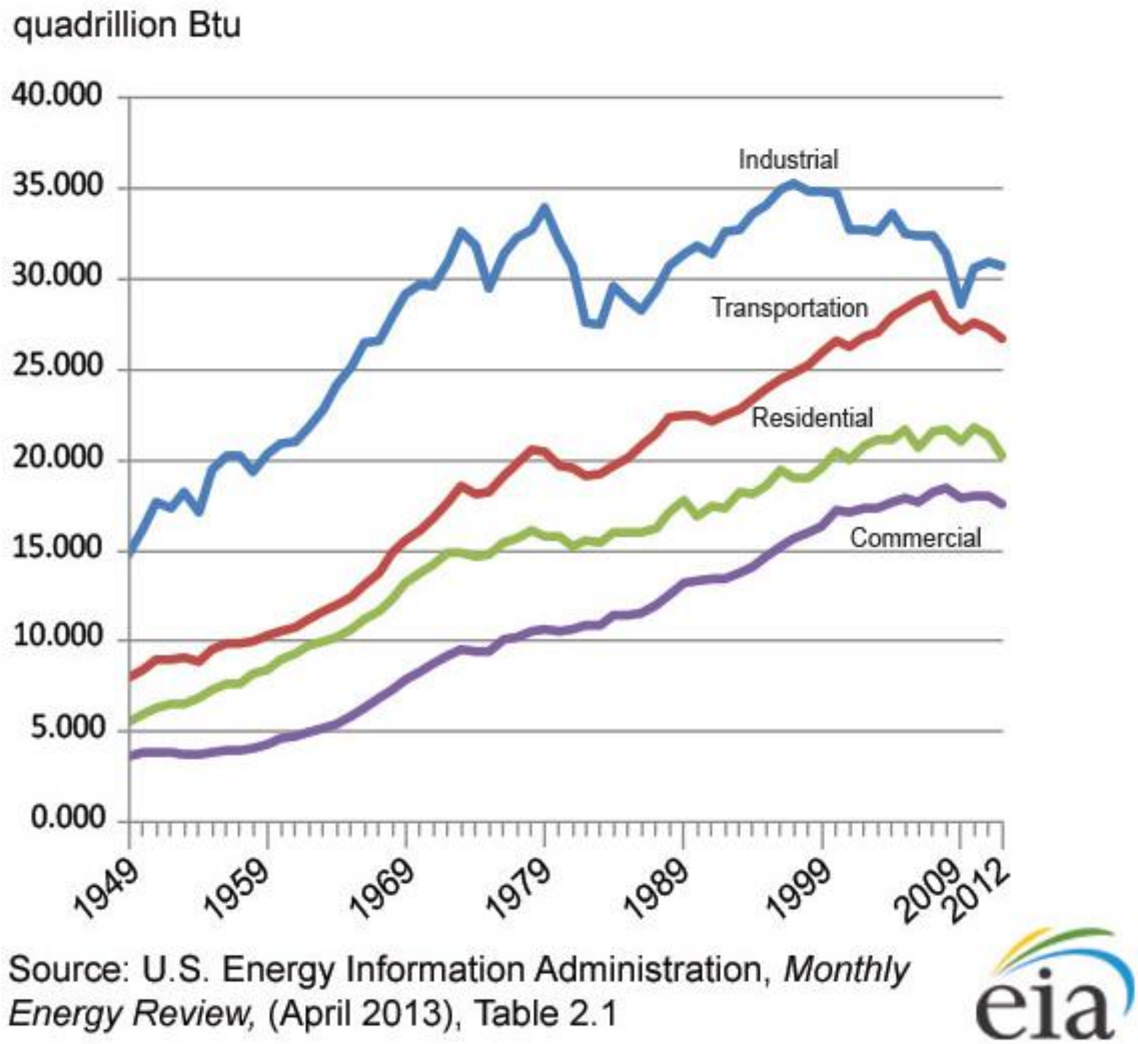
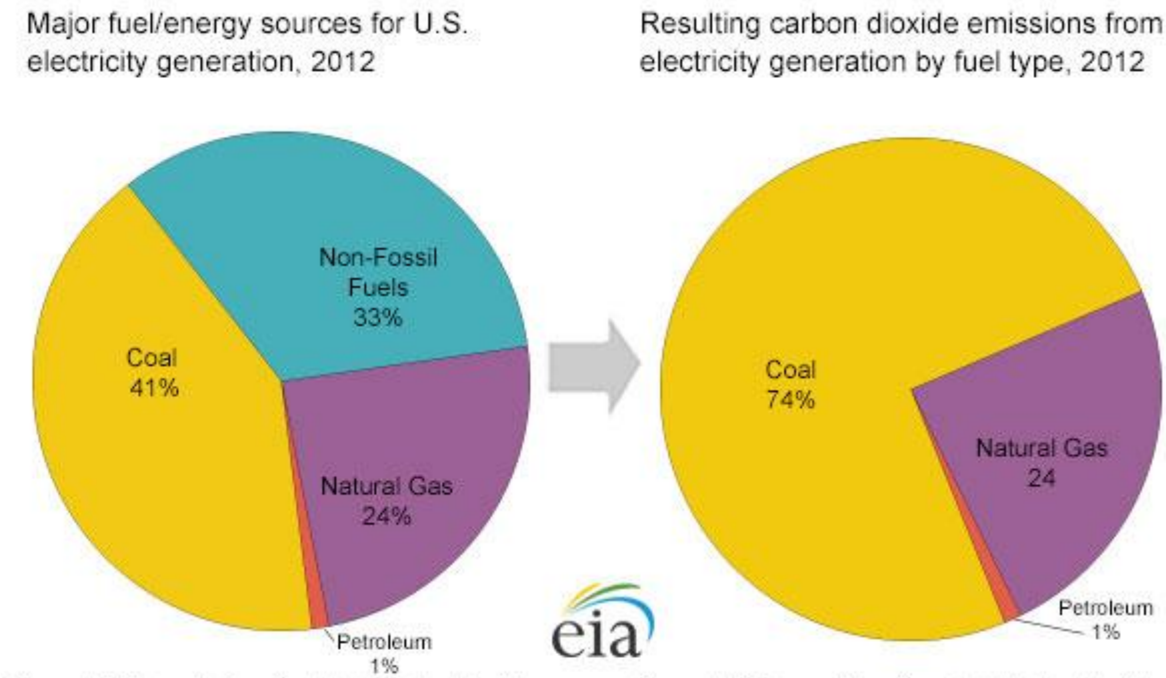


Figure 6: Fuel Sources of Electricity Generation and CO_2 Emissions by Fuel Type



Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 2.6 (May 2013), preliminary 2012 data.

Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 12.6 (May 2013), preliminary 2012 data.

Table 1: Texas Electricity Generator Composition (2005-2007)

	Total Capacity (MW)			Share of Capacity		
	2005	2006	2007	2005	2006	2007
Natural Gas	47537	48372	49109	67.20%	66.20%	64.80%
Coal	15229	15729	15762	21.50%	21.50%	20.80%
Nuclear	4887	4887	4892	6.90%	6.70%	6.50%
Wind	1545	2509	4150	2.20%	3.40%	5.50%
Unknown	856	856	1106	1.20%	1.20%	1.50%
Water	512	512	501	0.70%	0.70%	0.70%
Petroleum Coke	142	143	143	0.20%	0.20%	0.20%
Diesel	40	40	38	0.10%	0.10%	0.00%
Landfill Gas	40	53	59	0.10%	0.10%	0.10%
Total	70788	73101	75760	100.00%	100.00%	100.00%

Source: Cullen (2011).