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Comparing German and US Energy Transitions:

Centralized vs. Decentralized Government Approaches

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Comparing German and US Energy Transitions: Centralized vs. Decentralized Government Approaches

Senior Capstone Project for Sarah Greenway

ABSTRACT

The German *Energiewende* ("energy transition") is often credited with being the most ambitious renewable energy transition in the world. Germany's rapid transition is mainly led by their Renewable Energy Act of 2000, which has been amended several times in order to remain relevant during changing conditions. In contrast, the United States' energy transition seems stagnant and lacks an overall direction from the Federal Government. Despite this, the United States is making progress towards implementing renewable energy technologies due to the efforts of several states. Germany's transition has experienced a number of challenges along the way, while the United States' transition has benefited from the first-mover knowledge of Germany. This project will evaluate the two energy transitions using simple and complex indicators and determine which approach has been most effective: Germany's centralized approach or the United States' decentralized approach. It will then determine if either approach is sustainable. This project determined that Germany's centralized approach appears more effective. Additionally, results of a System Improvement Process (SIP) analysis shows that renewable energy cannot be developed sustainably at this time due to a number of barriers.

INTRODUCTION

The German *Energiewende* (translated to "energy transition" in English) is well known for being the most ambitious energy transition effort from a single country in the world. The goals of this energy transition range from increasing energy efficiency to phasing out nuclear energy. While there is some debate as to whether or not this transition is worth the effort, the outcome of this movement will have significant implications for the rest of the world.

While Germany has been a world leader in transitioning to renewable energy (with a 12.6% total primary energy consumption in 2016) (Wettengel), many people have criticized the United States for lagging behind (with a 10% total renewable primary energy consumption) (data.gov). The United States tends to be a leader in many aspects, but renewable energy is not one of them. While the United States is not a leader in the use of renewable energy, it cannot be said that the United States has sat idly by while the rest of the world advances further. A lack of overall direction from the Federal Government has led many individual state and local governments to begin to take action.

There are three main goals to my project:

1. Examine Germany's *Energiewende* and the United States' transition to renewable energy
2. Evaluate and compare the two approaches to determine which is more effective in their transition to renewable energy
3. Determine if either approach is sustainable

I chose to pursue this topic because I'm interested in what role renewable energy will play in the future of the United States. While the United States has begun to invest in renewable energy, what has been done so far does not seem that it is enough to make a difference. Fossil fuels bring a wide array of issues and complications, such as environmental concerns and energy security threats. Additionally, fossil fuels are a nonrenewable resource, so it is inevitable that the resource will run out at some point in time. It would be better to search for an alternative sooner, rather than later, as it would give ample time for planning and execution. I am interested in evaluating Germany's Energiewende because if it proves to be successful, then it would provide a model for the rest of the world to follow.

I think it is important to evaluate each method so that we have a clearer sense of direction about our energy usage. If it can be determined that the Energiewende has been more effective, then maybe the United States should consider implementing an environmental policy at the Federal level. However, if it can be determined that the United States' slower, decentralized method of energy transition has been more effective, then we should continue on the same path with increased efforts. Sustainability is also important to evaluate. If neither method is sustainable, then the renewable energy efforts will not be successful in the long run.

Research Questions

Based on the goals of this project, two separate, but equally important, research questions became evident.

1. Which approach is most effective?
2. Is either approach sustainable?

Hypotheses

The first hypothesis is that Germany's centralized approach is more effective in the transition to renewable energy. The second hypothesis is that both Germany's and the United States' renewable energy transitions are sustainable. These hypotheses were developed based on information learned in the Literature Review.

RESEARCH METHODOLOGY

This project will be conducted as a traditional research thesis, which involves conducting a literature review, developing a hypothesis, and testing the hypothesis.

Which Approach Is More Effective?

In order to evaluate the first research question, "Which approach is more effective?" I will be referring to the methodology outlined by the International Renewable Energy Agency (IRENA). The goal of this methodology is to evaluate policies used to guide the renewable energy transition. This methodology includes four main indicators:

1. Effectiveness
2. Efficiency
3. Equity
4. Institutional feasibility

Only the effectiveness section of this methodology will be used for this project. "Effectiveness" is measured by benchmarking the results of the renewable energy policies. They mention several simple methods of evaluating effectiveness, such as measuring capacity and output and the growth rates of each (IRENA 7).They also mention several complex methods for measuring effectiveness, including the European Commission's "Effectiveness Indicator," the "Deployment Status Indicator," and the IEA's "Policy Impact Indicator." This project will be using the simple indicator “Energy Consumed” and the complex indicator “Effectiveness Indicator.”

“Energy Consumed” (adapted from IRENA’s “Electricity Generated”) is preferred because there are very low data requirements for this metric. There is also no need for a specialist, as the data and results are simple to interpret. The simple indicator comes with a few limitations, however. First, the simple indicator does not consider the energy source as a percentage of total energy. Additionally, the simple indicators do not consider future growth or potential of the energy technology (IRENA 14).

In order to reduce some of the limitations of the simple indicator, a more complex indicator will be used. The “Effectiveness Indicator” was developed by the European Commission (EC) and is calculated as shown to the right:

where $$E_n^i = \frac{G_n^i - G_{n-1}^i}{ADDPOT_n^i} = \frac{G_n^i - G_{n-1}^i}{POT_{2020}^i - G_{n-1}^i}$$

E_n^i = Effectiveness indicator for RET i for the year n

G_n^i = Electricity generation by RET i in year n

$ADDPOT_n^i$ = Additional generation potential of RET i in year n until 2020

POT_{2020}^i = Total generation potential of RET i until 2020

The EC defines effectiveness as “the electricity delivered in GWh compared to the potential of the country for each technology” (IRENA 15). Thus, the Effectiveness Indicator measures generation achieved over a given period as a percentage of the total additional “realisable [*sic*] potential” (IRENA 15).

The drawbacks of the complex indicator are the significant data requirements and the complexity of the modeling method (IRENA 15). However, this metric may be better at comparing two countries of different sizes and ambitions, as the "realisable [*sic*] potential" is somewhat of an equalizing factor. While the complex indicator is an improvement on the simple indicator, it still cannot evaluate all factors. This is why the IRENA paper includes other metrics (efficiency, equity, and institutional feasibility) for evaluation as well.

Is Either Approach Sustainable?

In order to evaluate whether each transition is sustainable, I will be using the System Improvement Process (SIP) model (Thwink.org). This method involves a holistic approach by evaluating the three pillars of sustainability: benefits to society, economic value, and environmental integrity. A holistic approach is necessary to evaluate the sustainability of a project. The SIP model addresses four key areas:

1. How to overcome change resistance
2. How to achieve life form proper coupling (corporations vs. human interests)
3. How to avoid excessive model drift
4. How to achieve environmental proper coupling (environment vs. economy)

Answering the four questions, which identify the root causes, according to the SIP model, will help determine if each country's energy transition policy is sustainable. If there is no answer to one or more of these questions, then the method is not sustainable.

This methodology uses three key feedback loops to illustrate the root causes for a solution failure:

1. The Forces Favoring Change feedback loop
2. The Problem Commitment feedback loop
3. The Forces Resisting Change feedback loop

Identifying and resolving the root causes of the feedback loops listed above will allow for the solution of an identified problem.

LITERATURE REVIEW

Introduction

Germany has been in the spotlight recently for their efforts in the Energiewende. While their plans are ambitious, they have also been very costly. As first movers in the industry, they have had to suffer from unforeseen consequences of the transition. In contrast, the United States was late in the renewable energy transition, and has had fewer issues and lower costs. This project will evaluate both country's renewable energy transitions and conclude which approach has been more effective, and in addition if either transition is sustainable.

Background/History

The German Energiewende was spurred by various social movements in the 1970s, known as the New Social Movements (NSM). The most notable of these movements was an anti-nuclear energy campaign. Citizens were concerned about the construction of a new nuclear plant. Protesters infiltrated the plant to stop construction and were able to permanently halt construction after taking the utility company to court. After this event, citizens began to inform themselves about the dangers of nuclear energy, not only with the production, but also with the radioactive waste disposal (Hockenos).

Germany and other countries were greatly affected when Middle Eastern countries drastically increased oil prices in 1973. This event is commonly known as the oil crisis of 1973.

Germany's response to this crisis was to increase nuclear energy production in an effort to increase energy security. This only further intensified the protesters fears of nuclear energy. The decision to increase nuclear energy production caused a monumental environmental movement, resulting in the formation of the Greens, an environmental political party. The nuclear disaster at Chernobyl only helped the Greens gain momentum, as it really showed the Germans how dangerous nuclear energy truly is.

It was not until the 2000s, however, that a definitive energy plan, called the Energiewende, was set in motion (Hockenos). This plan was mainly backed by the *Erneuerbare-Energien-Gesetz* (EEG), a national energy plan known as the Renewable Energy Act in English. The EEG was first enacted in 2000, and has since been amended several times, with the most recent amendment in 2017. The Energiewende goals each involve cleaner and safer energy for the German people. They also consider the environmental impacts of renewable energy as well. The goals set forth in this policy are as follows:

- Phase out nuclear power by 2022
- Reduce primary energy use by 50% by the year 2050 compared to 2008 levels
- Reduce greenhouse gas emissions by 80% by the year 2050 compared to 1990 levels
- Achieve a renewable energy consumption of 60% by 2050
    - Achieve 80% renewably generated electricity consumption by 2050 (Agora Energiewende)

The United States' energy transition greatly differs from that of the Energiewende. While the Energiewende is backed by specific policies and goals, the United States has not implemented a national policy of the same scale. There have still been some sizeable investments by the U.S. Government, however.

In 2009, President Obama invested $90 billion in renewable energy and in 2015 Congress began giving renewable tax credits to individuals who installed renewable energy generating systems. President Obama is also responsible for starting the first offshore wind farm in the United States. Under the Obama Administration, carbon emissions from electricity decreased approximately 9% and the economy grew 10% (Sargent). This is a good sign, as it indicates that emissions are decreasing, but not at the expense of the economy.

While the Federal Government has been involved to some extent, there has been considerable progress made by some individual states. President Obama was dedicated to investing in renewable energy, but the direction has changed now that President Trump is in office.

The German Energiewende

The German Energiewende is well known for being one of the most ambitious energy transition policies in the world. While some argue that their goals are not sufficient, Germany has set the most ambitious goals of any country. They set out to attain their goals, despite the high costs and many unknowns of the renewable energy industry at the time.

David Buchan, a specialist in the energy and climate policy of the European Union, describes how Germany had a first-mover disadvantage in their renewable energy transition. He says that this disadvantage was magnified by the speed with which Germany is trying to create change. Germany has already had to provide expensive subsidies for solar PV generation. (Buchan 4). These are large disadvantages for Germany, and ultimately these disadvantages increase the costs that Germany will incur in this transition. This is good news for the United States, however, because Germany has already invested in developing the technologies necessary for a renewable energy transition. The resulting large scale production of these renewable energy technologies also decreased purchase and implementation costs.

Buchan also notes that the Energiewende's success is largely due to its public participation. In 2010, citizens owned 40 percent of Germany's 53 GW renewable energy capacity (Buchan 10). The big four energy companies only owned about 7 percent (Buchan 10). This vast difference in ownership is one of the main reasons behind the policy's success thus far. With citizens investing in renewable energy themselves, it takes some of the burden away from the federal government in funding these projects. The citizens that invest in these projects are benefitting from the feed-in tariff that was implemented in 2000. Essentially, citizens were paid a fix price by the German government for their renewable energy production.

Germany has found success in implementing a feed-in tariff for citizens who participate in the energy production. The feed-in tariff was first implemented in 2000 and has been amended a couple times over the years. This policy allows everyday citizens to invest in the renewable energy transition and be rewarded for it. This policy was key in spurring public participation in the Energiewende (World Future Council).

Germany's feed-in tariff has since been replaced with an auction system as part of the 2017 revision to the Energiewende. Small installations of less than 750 kW will be allowed to remain on the feed-in tariff system, however. The reasoning behind the change was to make it easier for Germany to control the development of renewables. Payments for renewable installations will be determined by the market instead of a fixed price by the government, as it was with the feed-in tariff (Appunn).

Germany's rapid transition to renewable energy has caused German households to pay one of the highest rates for power in the world. What is atypical about this energy transition is that Germans pay one of the highest per-unit rates for power, yet they still support the Energiewende. Jeffrey Ball discusses this high per-unit rate of power further. He mentions that in 2016, 25 billion euros were spent on renewable energy. 23 billion euros of this came directly from consumers paying an energy surcharge on their electric bill. German households have seen a 50% increase in their electric costs since 2007 alone, mainly due to the efforts of the Energiewende (Ball).

Beveridge and Kern outline several of the challenges of the Energiewende, which are mainly technological and management related. One of their main issues is the limited generating capacity of the renewable energy. Craig Morris believes that blackout times are a major issue with the Energiewende. He refers to this issue as the "central technical challenge" (Morris). There tends to be blackout periods where energy is not being generated, due to factors such as lack of sun or lack or wind. Because of these blackout periods, Germany will need to look into grid development and storage capacity in order to obtain maximum efficiency. (Beveridge and Kern 9).

Ball also mentions another central issue of the Energiewende. Conventional power plants still have to be available to cover the blackout periods of renewable energy. However, these power plants are no longer seeing the same high rate of return. They are being forced to compete on the lower price due to many residents producing their own power. These plants need to stay open in order to cover the blackout times, but they are making far less money than they once did (Ball). It also requires an incredible amount of planning and forecasting to determine when these blackout times are going to occur. This is yet another cost that has to be incurred for the Energiewende.

Andreas Becker also discusses the major costs of the Energiewende. Germans were told this transition would only cost 1 euro extra per month. This has been far from the truth; there has already been 150 billion euros spent on the Energiewende as of 2017, and this number is expected to reach half a trillion euros by 2025. Instead, German households have already seen their electricity bills double, which is far from the 1 euro a month that they were promised. Not only have the costs been high, but Germany has not really helped the environment. Because of the blackout times, Germany is forced to keep their conventional power plants open. These power plants are still creating energy, which is then exported to other countries. So while Germany may seem like they are reducing emissions from their own energy consumption, they are really passing additional carbon emissions onto other countries (Becker).

Martin outlines this issue further. Despite using more renewable energy, Germany's carbon emissions rose due to producing more power than needed. Due to blackout periods, conventional power plants are still required. This leads to times where they are producing power that is not needed. This excess production is not only bad for the environment, but it leads energy companies to have to essentially pay customers to consume electricity. A stipulation of the Energiewende is that renewable energy must be used first, before conventional energy production methods. This leads to the energy produced through conventional methods to be exported, as Germany does not need all the energy they are producing (Martin).

Archer and Banks attribute Germany's success thus far to its policies that keep the Energiewende on track and provide a method of accountability. They also mention that the Energiewende has been successful in creating new, clean jobs and promoting a new industry while also enhancing energy security. Another strength of the Energiewende is that their policies are widely supported. Without support for a policy, it is not likely to succeed (Archer and Banks). Germany is constantly making revisions to their policies in response to changing conditions and further advancing the Energiewende.

Archer and Banks also make the point that because Germans, on average, consume less electricity, they are less sensitive to price increases that were created by the Energiewende. If United States consumers had to cover all of the start-up costs that Germany incurred, they would likely be unhappy. They also warn that rapid transition brings reliability and efficiency into question, and as previously mentioned, because Germany is transitioning so quickly, multiple technical issues (e.g. blackout periods) have arisen (Archer and Banks).

<u>The United States' Energy Transition</u>

While many think that the United States is lagging behind in the renewable energy transition, they have made considerable progress. By being a late mover, some would argue that the United States has made it easier to transition. For example, the costs have been drastically reduced since Germany started their renewable energy transition in 2000. While the Trump Administration is not fully committed to continuing this transition, many states have taken it upon themselves to continue it. Different states have different reasons for transitioning to renewable energy. For example, California's transition is motivated for environmental reasons, whereas Texas' transition is mainly led by market forces. Overall, progress has been made towards renewable energy use in the United States.

One article, "What Germany's Energy Transition Means for the United States," sees a positive outlook for the United States. Germany has already made large investments in renewable energy technologies, making it cheaper for other countries wishing to implement them. As of 2015, the cost of solar technology has decreased 80% and the cost of wind technology has decreased by 60% since 2009 (Bertram). Germany had to pay a much higher cost for the same technology that we can now implement in the United States.

Bertram's major source of optimism was President Obama's Clean Power Plan which is currently in the process of being repealed under the Trump Administration. Although the plan may be repealed, it has initiated change that many states plan to continue. Certain states' efforts to cut carbon emissions and implement renewable energy allow Bertram to remain optimistic. In these efforts, California is the frontrunner of the United States. As of 2015, the United States has been investing more annually in renewable energy than Germany. State participation in transitioning to renewable energy shows that although the United States does not have a national policy in place, the states are still acting with renewable energy in mind.

Winland also maintains a positive attitude about the United States' energy transition. Due to the cheaper costs of natural gas and renewables, the number of coal power plants is decreasing. Like Bertram, she also credits much of this transition to Obama's Clean Power Plan. She remains hopeful that a transition away from fossil fuels is possible. She believes that there are three key factors in this transition:

1. A consistent and long-term commitment from the public sector
2. Market forces
3. Support and funding from impacted communities

Winland believes that despite Trump's lack of direction, the transition towards renewable energy will continue (Winland).

In March 2017, the United States set a record for generating 10% of electricity using wind and solar power (8% wind and 2% solar) (Gibbens). This was mainly led by Texas and Iowa. Like Winland, Gibbens believes that with solar and wind becoming more competitive than coal, the Trump Administration pulling out of the Paris Agreement will have a minimal impact. The private sector is naturally gravitating towards renewable energy without a policy in place (Gibbens).

Nippa and Meschke argue that the success of an energy transition in any country rests on the shoulders of the political system, mainly because there needs to be a governing body watching over the transition. The political system, however, needs to have an agreement as to what energy transition will take place and how to achieve the transition. Without these agreements, it will be far more difficult to get anything done, especially in countries where elections take place every four to five years (Nippa and Meschke 3509).

These political challenges have taken place in the United States just in the past few years. President Obama and President Trump have very different attitudes towards energy. President Obama wanted to leave behind a legacy of renewable energy and lower emissions, as evidenced by his Clean Power Plan. President Trump has very little interest in renewable energy, as he's indicated in a number of different ways.

First, President Trump has withdrawn from the Paris Accords, an agreement that was meant to hold countries around the world accountable for the emissions that they create. He has also requested the repeal of Obama's Clean Power Plan, a policy created to hold the United States accountable in the Paris Accords. Additionally, he rescinded the coal moratorium, which makes it easier for companies to mine for coal on Federal lands (The White House). Everything that President Trump has done in regards to these energy policies was in favor of creating more jobs and growing the economy, rather than protecting the environment or growing the United States' share in renewable energy.

Nippa and Meschke do not argue, however, that this governing body needs to be the Federal Government. At this point in time, it appears that the United States' energy transition is more led by state and local governments than by the Federal Government. With a lack of direction from the Federal Government, many states have taken matters into their own hands.

California, for example, has committed to attaining 100% renewable energy by 2045 (Nace). While this will bring benefits such as less pollution, less carbon emissions, and greater energy security, there are also many costs that come along with this. In 2017, California imported 33% of its energy, 6% of which is from coal. In 2010, only 25% of energy was imported. According to Nace, this is not a good trend for California to be following if California is to become self-sustaining in terms of energy usage. Moreover, California also faces the issue of being the third largest oil and gas producer in the United Sates, which amounts to about 456,000 jobs and 3.4% of their GDP (Nace).

Nace also mentions that Texas is similar to California, noting that both states are oil and gas producers with large populations. They differ, however, in their mentality on the transition. California is in search of a cleaner environment, whereas Texas sees the transition as an economic opportunity (Nace).

One of Texas' main advantages is the Electric Reliability Council of Texas (ERCOT), which created and manages the deregulated marketplace for energy. Texas mainly relies on market conditions for their clean energy. Lippincott predicts that if natural gas prices remain low and solar PV prices continue to decrease, then market conditions will force a cleaner grid. He predicts that costs of a cleaner grid will remain about the same as they are today. Texas has been relying on their own production of natural gas instead of more expensive coal. Lippincott also predicts that environmental regulations will have little impact on Texas' efforts, as they are already moving towards a cleaner system on their own.

Hawaii has the same goal as California: 100% renewable electricity by 2045. Hawaii's current energy mix consists of bioenergy, geothermal, hydroelectric, hydrokinetic, wind and solar. As of 2015, their largest source of renewable energy is solar. In fact, Hawaii has the most solar capacity per capita in the United States (La Shier). The state was able to initiate this transition due to already high energy prices, offering many credits in order to influence consumers to install renewable energy systems. The state's main challenge right now is the separate, centralized grids (La Shier). Having a grid that no longer fits a state's needs is a common theme for renewable energy transitions.

In 2016, wind and solar made up 61% of new electricity generating capacity in the United States, which is mainly caused by the decreasing costs of the technologies (Clean Edge, Inc.). The United States was slow to start the transition, but it has since taken off. Iowa, South Dakota, and Kansas all use more than 30% renewables, and Oklahoma, North Dakota, and California use 20% (Clean Edge, Inc.). Many states have been increasing the workforce in clean jobs as well, with Vermont, Rhode Island, Utah, Michigan, Oregon, and Massachusetts having the most clean energy jobs (Clean Edge, Inc.).

David Wogan, a policy researcher, noted that the United States typically only goes through an energy transition when it is necessary. An example of this is transitioning away from fuel sources such as wood due to finding cheaper and more abundant resources. He believes that this phenomenon is likely to continue in the future (Wogan). Building on this idea, it would appear that the United States will not fully transition away from fossil fuels until it becomes much cheaper than fossil fuels.

Dale Medearis has a similar viewpoint to Wogan, in that he does not believe a national energy transition will occur at this point in time. He cites that the United States is not "problem-focused or goal-oriented." (Medearis 171). He holds a pessimistic view of the government's ability to implement any strategies. He believes that the United States' efforts fail because policymakers often try to copy an idea, rather than making it their own. Additionally, due to the idea of American exceptionalism, he feels that the United States will never fully appreciate the work of other countries. (Medearis 178).

Steven Cohen would also agree that an energy transition in the United States is not practical right now, but he also believes that there is hope. He cites the reasons behind this road block as:

1. Technologies that still need advancing
2. Infrastructure that is not designed for distributed generation
3. Complicated political challenges that limit our ability to make the tough choices necessary for long-term energy policies (Cohen 689)

Cohen believes that until the price of renewables is significantly lower, the United States will not fully transition away from fossil fuels. He says that as long as fossil fuels are available, the United States will continue to use them. Cohen agrees with Wogan that the United States will not transition until it becomes a necessity. Cohen says that we have to "convince companies that have billions of dollars in sunk costs in the current energy system to stop lobbying against renewable energy and start investing in it." (Cohen 691). As long as the energy companies are lobbying for fossil fuels, it seems that it will be difficult to fully invest in renewables.

While some have pessimistic views on the energy transition of the United States, the data has shown that there is slow progress towards the direction of renewable energy. It may not be at the same pace or as wide-spread as the Energiewende, but it may be the best that can be done at this point. Many states are committed to the energy transition in some way or another. Not all of the states involved have been mentioned, but the goal is to evaluate the United States as a whole and not on the state-by-state level. Research on some specific states is included for the sole purpose of evaluating to what extent singular states have started their involvement in the transition.

Conclusion

Germany and the United States have had very different energy transitions. Germany's was driven by rapid social change and was backed by the government. Policies were made in order to ensure the success of the transition. Germany's energy transition was very costly due to technology that needed advancing, and they continually have to come up with solutions to unforeseen problems.

The United States has only recently begun larger investments in renewable energy. These investments were started by President Obama's Clean Power Plan, but the Trump Administration has since taken a step away from environmental concerns. With a lack of direction from the Federal Government, individual states have begun the transition on their own. Some states have created policies to ensure that these transitions have taken place, and other states have let market conditions determine their energy mix.

RESULTS & DISCUSSION

Research Question 1: Simple Indicator: Energy Consumed

First, the two energy transitions were evaluated using the simple indicator, "Energy Consumed," as discussed in the *Methodology* section. The years 1990-2017 were evaluated. This range was chosen based upon the official start date of the Energiewende, with the implementation of the Renewable Energy Act of 2000. Data began in 1990 as a means of evaluating the conditions prior to the start of this policy. Linear trend lines were then inserted, with a projection until the year 2030. This projection is meant to serve as a rough estimate, and the energy consumption cannot be expected to perfectly follow this trend line as different factors will affect how the trends continue in the future.

Germany's data was collected from Germany's BMWi (Federal Ministry for Economic Affairs and Energy) Table "Primary Energy Consumption by Energy." This table, originally displayed in German, was translated to English using Google Translate. The data was originally displayed in Petajoules (PJ), but was converted to million Kilowatt Hours (million kWh) in order to be comparable to the United States.

The United States' data was collected from the United States' EIA (Energy Information Administration) Table 1.3 "Primary Energy Consumption by Source." The data was originally displayed in quadrillion British Thermal Units (BTU), but was also converted to million kWh.

Both data sets were also displayed in kWh per capita as a means of making the data more comparable. The United States and Germany have very different populations in terms of size, and the United States is experiencing an increasing population, while Germany's population is decreasing. Populations were acquired from The World Bank.

Additionally, the data for Germany and the United States had to be grouped into comparable categories (Appendix A). Refer to Appendix B and Appendix C for raw data and Appendix D for processed data.

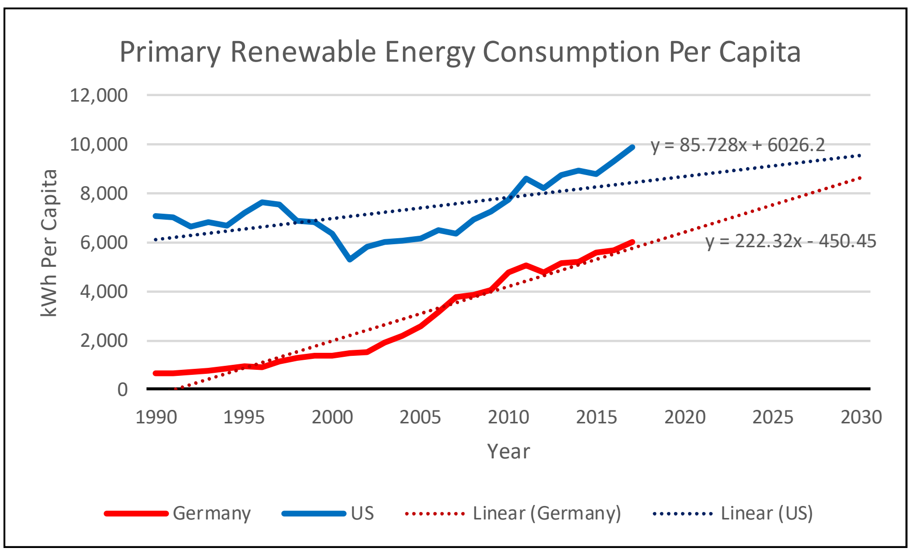


Figure 1: Primary Renewable Energy Consumption Per Capita (1990-2017)

First, Germany and the United States were compared on their primary renewable energy consumption per capita. The first notable thing about this graph is that the United States' primary renewable energy consumption has followed two distinct trends: an overall decrease from 1990-2001, and an overall increase from the years 2002-2017. This is in contrast to

Germany's trend, which has been gradually increasing since 1990. The slope of the United States' trend is 85.728x, compared to Germany's slope of 222.32x. Essentially, the United States averages an 86 kWh per capita increase in renewable energy consumption each year and Germany averages a 222 kWh per capita increase each year. These slopes indicate that Germany is increasing renewable energy consumption at a faster rate than the United States.

Additionally, Germany's percent increase from 1990-2017 was 773%, vs. the United States' percent increase of 40%. This is a significant difference between the two countries, however, Germany began in 1990 with a much smaller kWh per capita (687 kWh per capita compared to the United States' 7,091 kWh per capita). It should be expected, however, that growth of renewables is normally greater at the beginning stages of an energy transition when there is room to grow.

Another thing to notice about this graph is that the United States has a much higher renewable energy consumption per capita than Germany (ranging from approximately 5,300 kWh per capita to 10,000 kWh per capita compared to Germany's range of 700 kWh per capita to 6,000 kWh per capita). This can be partially attributed to the overconsumption of energy in the United States. It is a well-known fact that the United States uses more energy than other countries. In 2015, the United States' primary energy consumption made up 18% of the world's energy consumption, while only making up approximately 5% of the world population (AGI).

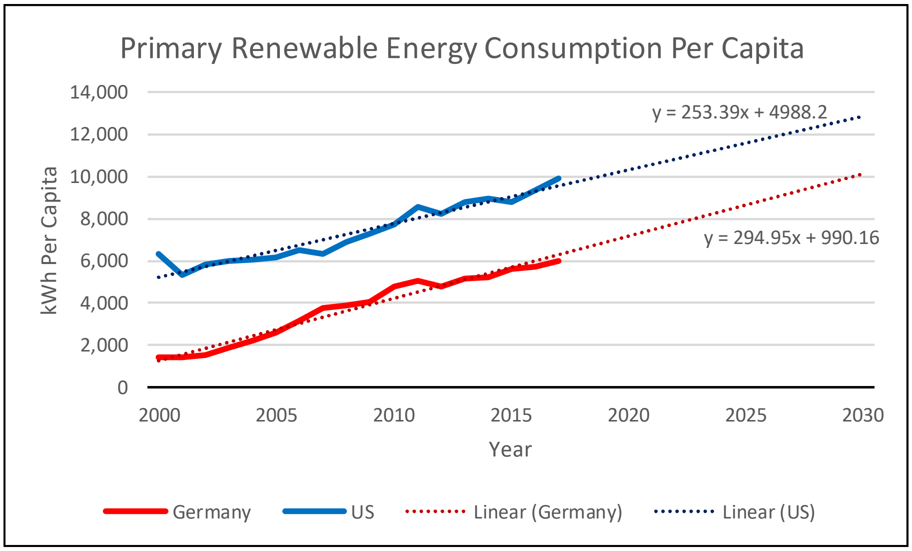


Figure 2: Primary Renewable Energy Consumption Per Capita (2000-2017)

This graph is the same as the previous graph (Figure 1), except it has been isolated to only show the years 2000-2017, which is when the United States experienced an increase in primary renewable energy consumption. In this period, the trend line for the United States has a slope of 253.39x compared to the slope of Germany's trend line, 294.95x. Both the United States' and Germany's slopes increased in this graph compared to the previous graph, indicating that renewable energy has been implemented at faster rates from 2000-2017 than from 1990-2017. This makes sense when considering that Germany's Energiewende did not officially start until 2000.

Additionally, half the United States growth in renewable energy since 2000 can be attributed to the Renewable Portfolio Standards (RPS) (Barbose 3). RPS are implemented on the state level and require that electric companies use a certain percentage of renewable energy to create their energy supply. Different fees may be applicable for noncompliance. Currently, 29 states and D.C. participate in RPS, with each state having different requirements and goals for the RPS.

Germany's percent increase from 2000-2017 was 326%, compared to the United States' percent increase of 56%. Compared to the previous graph that shows primary renewable energy consumption from 1990-2017, this is a 447 percentage point decrease for Germany and a 16 percentage point increase for the United States. So, while Germany's rate of change is marginally larger than the United States' in this case, Germany's percent change is still much higher.

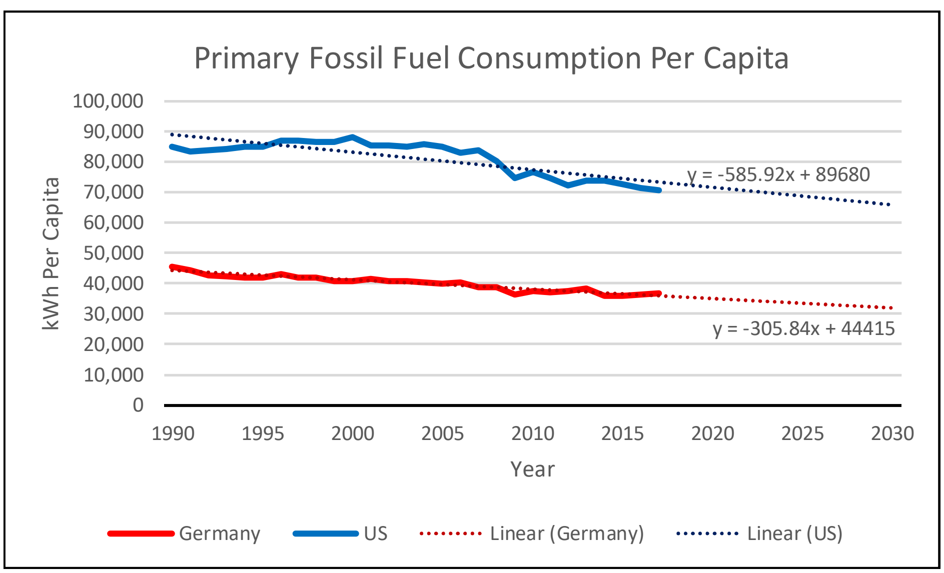


Figure 3: Primary Fossil Fuel Consumption Per Capita (1990-2017)

The primary fossil fuel consumption per capita graph is interesting because the United States is decreasing their fossil fuel consumption at a faster rate than Germany. These results were unexpected because the Energiewende is attempting to increase the renewable energy share in Germany, which should decrease the fossil fuel share. Thus, we would expect Germany to be decreasing fossil fuel consumption at a faster rate than the United States, who does not have a federal policy on renewable energy consumption. This graph shows that this is not the case: Germany's rate of change of -305.84x is less than the United States' slope of -585.92x.

While on a kWh per capita basis, the United States is decreasing at a faster rate than Germany, this is not the case when percent decrease is considered. From 1990-2017, Germany had a 19% decrease in fossil fuel consumption per capita, where the United States had a 17% decrease. So, while the United States is decreasing more kWh per capita per year, Germany has done a more effective job at decreasing fossil fuels percent wise.

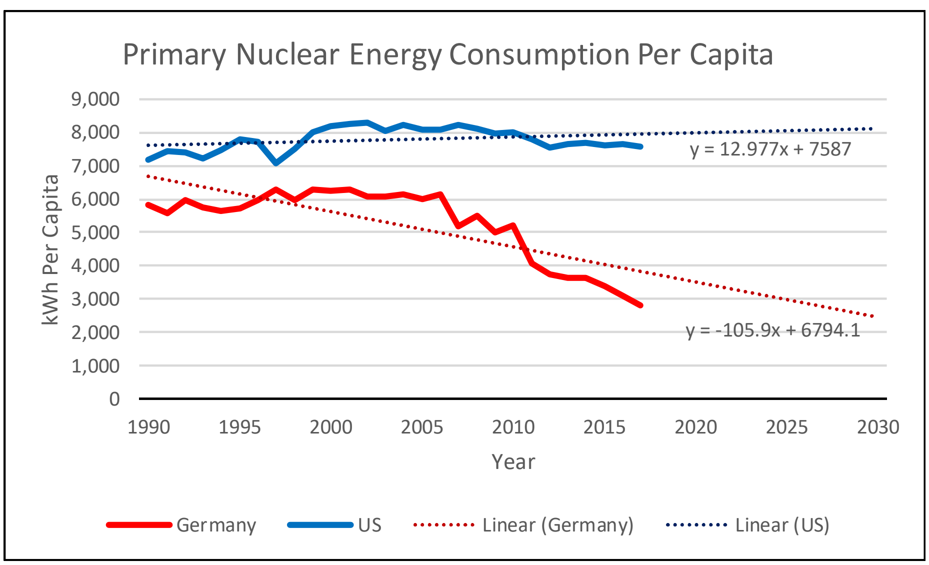


Figure 4: Primary Nuclear Energy Consumption Per Capita (1990-2017)

The primary nuclear energy consumption per capita graph correlates to what the literature review concluded. Because of Germany's goal to phase out nuclear energy by the year 2022, it would be expected that their nuclear energy consumption would decrease at the drastic rate shown in the graph above. The United States' nuclear energy consumption has remained pretty constant since 1990, which was also expected because the United States has no real intent on decreasing or increasing nuclear energy consumption in the future.

Germany's slope is -105.9x, with the largest decreases occurring from 2005-2017. It should be noted that Germany's trend line is not a close fit due to noticeably different trends from 1990-2005, and from 2005-2017. For this reason, a separate graph was made to isolate the years 2005-2017 (Figure 5). Germany's large decrease is mainly because the Renewable Energy Act of 2000 banned future construction of nuclear power plants. They also set a goal of phasing out nuclear energy altogether by the year 2022. This means that all nuclear power plants will stop operations by 2022. The United States' slope is 12.977x, indicating that their nuclear energy consumption has remained fairly constant since 1990, with a slight increase. Germany's nuclear energy consumption experienced a 52% decrease from 1990-2017, while the United States experienced a 6% increase.

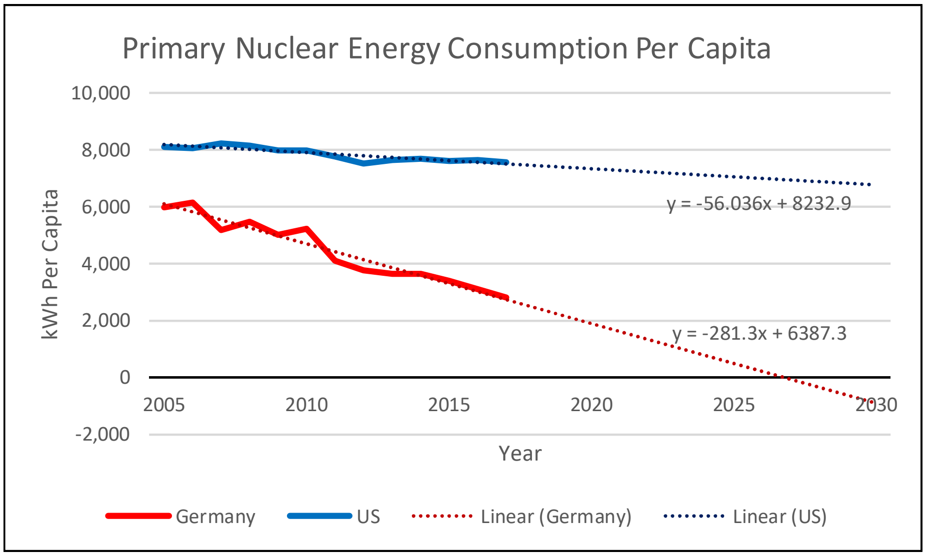


Figure 5: Primary Nuclear Energy Consumption Per Capita (2005-2017)

In Figure 4, Germany's trend line did not closely fit the data from 1990-2017. Because of this, another graph was compiled beginning with the data in 2005. Germany's trend line fits much better in this case, with the trend line closely following the data. In this graph, Germany's slope is -281.3x, compared to the United States' slope of -56.036x.

Germany's percent decrease of nuclear energy consumption for this period was 53%. The United States also had a percent decrease in this case, which was 6%. Again, these results were to be expected, as Germany's goal is to phase-out nuclear energy consumption by 2022 and the United States does not have a real goal regarding nuclear energy consumption.

Figure 4 indicated that the United States was gradually increasing nuclear energy consumption from 1990-2005. This graph tells us that the United States has very gradually began to decrease their nuclear energy consumption since 2005.

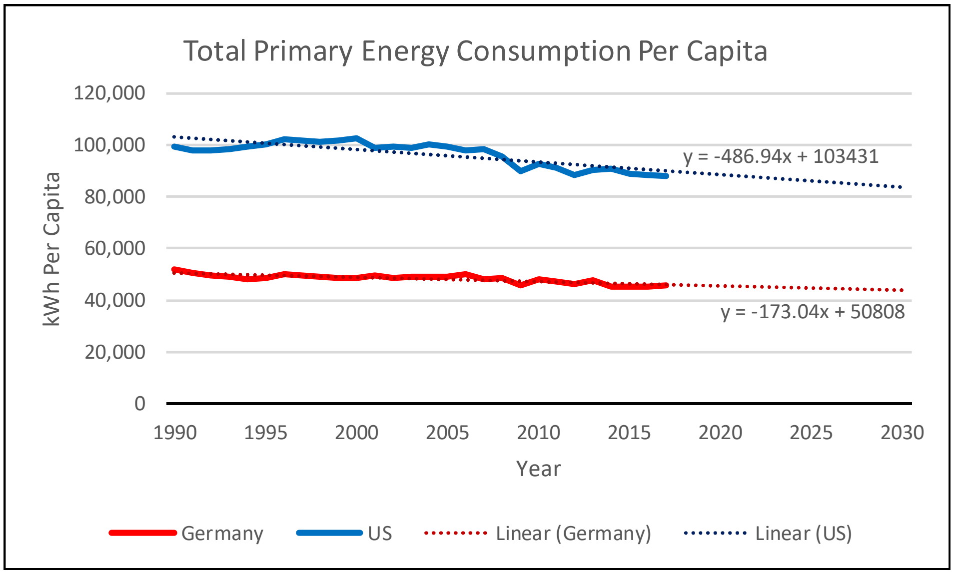


Figure 6: Total Primary Energy Consumption Per Capita (1990-2017)

The total primary energy consumption per capita graph is interesting for a number of reasons. First, the United States is decreasing their primary energy consumption by a slope of -486.94x and Germany is decreasing by a slope of -173.04x. This is strange, considering that Germany has the goal of reducing primary energy use by 50% by the year 2050 compared to 2008 levels. It would be expected that Germany would be decreasing primary energy consumption faster than the United States, especially because the United States has no goals of decreasing energy consumption.

It may be argued that perhaps it is easier for the United States to decrease energy use in general because of the overconsumption in the United States. Therefore, the United States could simply decrease their overconsumption. It may be harder in Germany to decrease energy usage because they may have to increase energy efficiency if they are already at the bare minimum energy usage.

While the United States has a much higher decrease per year in total primary energy consumption per capita, evaluating percent change from 1990-2017 returns slightly different results. Germany's total primary energy consumption decreased 12%, where the United States' decreased 11%. So, although the United States is showing more rapid decreases in kWh per capita, Germany shows a faster decrease in terms of percent change.

Research Question 1: Complex Indicator: Effectiveness Indicator

Next, the two energy transitions were evaluated using the complex indicator, "Effectiveness Indicator," as discussed in the Methodology section. Data regarding the United States' renewable electricity consumption was gathered from the EIA's Table 10.2c. Data regarding Germany's renewable electricity consumption was gathered from BMWi's "Renewable Energy Sources in Figures."

"Realisable [*sic*] potential" for this evaluation is considered to be the country's goal for renewable energy electricity consumption for the year 2030. For the United States, this number came from the Paris Accords, and Germany's came from the goals of the Energiewende. It should be noted that the goals of the renewable energy share for 2030 vary and can be found from a number of sources. Using the goals as specified in the Paris Accords for the United States and updated Energiewende for Germany seems to be a good starting point for this study.

The effectiveness indicator will indicate an effective policy if the calculation is:

- Above 7% for mature technologies (wind and hydropower)
- Above 3% for moderate technologies (biogas)
- Above 0.5% for immature technologies (solar photovoltaic)

The results of this indicator are shown to the right in Figure 6. Both the United States' and Germany's renewable energy "policies" are deemed to be effective based on this model, although the effectiveness guidelines were developed in 2005 and are therefore conservative. Germany's model, however, can be seen as more effective due to the higher percentages. It is interesting to note, however, that even though the United States does not have a national renewable energy policy, they are still implementing renewable energy technologies at what is considered to be an effective rate. In other words, according to the effectiveness indicator, a lack of a national renewable energy policy has been effective for the United States.

	Germany	US
Solar	57.50%	1.48%
Wind	23.24%	10.63%
Solar & Wind Mix	36.40%	4.29%

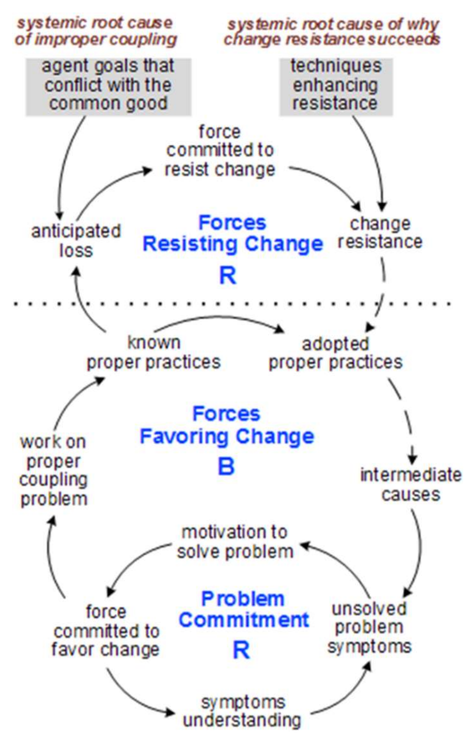
Figure 7: Effectiveness Indicator

Additionally, Germany actually surpassed their "realisable [*sic*] potential" for solar in 2013 and wind in 2015. This may be due to a number of reasons. First, Germany may be implementing renewable energy at a faster pace than previously expected, thus making their estimates outdated. Additionally, "realisable [*sic*] potential" is typically determined by experts who have done extensive research of barriers to implementation, market growth rates, and technological potential. Using estimates on expected energy demand may not be the most accurate method of identifying "realisable [*sic*] potential," thus explaining why Germany has already reached this number.

It should also be noted that, for 2030, the United States' renewable energy goal is 20% of electricity demand, where Germany's is 55% of electricity demand. So, Germany is reaching its higher target more effectively than the United States is reaching its lower target.

<u>Research Question 2: Is Either Approach Sustainable?</u>

In order to evaluate if either approach is sustainable, the System Improvement Process (SIP) model will be used (as outlined in the Methodology section). This method first involves evaluating feedback loops, as shown to the right. In the middle is the "Forces Favoring Change" feedback loop. This feedback loop first begins with "intermediate causes," of the main problem "fossil fuel dependency." The proper practice is to replace fossil fuels with renewable energy. It is imperative to determine if renewable energy has the ability to replace fossil fuels in a sustainable manner. Some key



symptoms of this problem are fossil fuel dependency and the externalities that come with fossil fuel use (climate change, pollution, health effects, etc.).

An increasing number of symptoms will activate the "Problem Commitment" feedback loop. This loop will remain in effect until there is a force committed to favor change. This will then activate the "Forces Favoring Change" feedback loop. The first step once this feedback loop is activated is to work on the proper coupling problem. Specifically, this refers to the to life form proper coupling (corporations vs. human interests) and environmental proper coupling (environment vs. economy).

When individuals anticipate loss, the "Forces Resisting Change" feedback loop is activated. If the force committed to resist change is large enough, it will result in a solution failure. "Agent goals that conflict with the common good" is the systematic root cause of improper coupling. In order to ensure the "Forces Resisting Change" feedback loop does not control the system, the forces resisting change must be known in order to find and resolve the root cause of these forces. Until the root cause is addressed, the solution is bound fail.

The root causes for growth of the forces resisting change feedback loop must be determined and addressed to keep the feedback loop at an acceptable level. These root causes are "agent goals that conflict with the common good" and "techniques enhancing resistance."

In regards to sustaining renewable energy, there are many agent goals that conflict with the common good. Sathaye, Lucon, & Rahman indicate that, generally, people view renewable energy as favorable for the environment, and the general public supports renewable energy. There is a disconnect, however, in the sense that people generally do not agree with renewable energy developments in their own communities. This is commonly known as the "not in my backyard" mentality. There will often be social resistance of renewable technology implementation when it will affect biodiversity, ecosystems, landscape, water and land use, and availability of land (Sathaye et al. 72).

Additionally, fossil fuel companies are in the business of making money. These companies place profits as a priority. As long as fossil fuel are more profitable for them, they will not see renewable energy as a viable solution to the externalities of fossil fuels.

A few other agent goals conflicting with the common good include climate change deniers and the political system. Climate change deniers are generally against renewable energy, as they do not see the benefits of implementing renewable energy. Politicians do not always have the publics best interest in mind, as they will implement policies that their political party agrees with. Additionally, different parties have differing views on renewable energy and the environmental impacts of fossil fuels.

Renewable energy also comes with a number of techniques enhancing resistance. The major resistance for implementing full-scale renewable energy is the technological barriers. Renewable energy is not always being generated, as there are blackout periods where the sun is not shining and the wind is not blowing. In order to cover these blackout times, conventional power plants are currently needed to meet energy demand. Another technological barrier relates to the current energy grids that exist in many countries. These grids are not designed to support renewable energy technologies, and often there is not enough storage capacity to accommodate renewable energy generation.

Another technological barrier is the high initial investment that renewable energy requires. Some individuals may not see the benefit in renewable energy implementation when there is already a current energy system in place that is functional. Renewable energy implementation requires a completely new investment, and often this would require ignoring the sunk costs of the current energy system.

Due to the number of forces resisting change, renewable energy development may not be currently sustainable according to the SIP model. There are too many factors at this time working against sustainable renewable energy development in general. The United States and Germany may have slightly differing degrees of these forces resisting change, but overall these factors are relevant to both countries. It is a good sign, however, that these forces resisting change have been identified. Because the forces resisting change are known, efforts can be made to reduce these forces to an acceptable level and attain sustainable development. Additionally, the fact that both countries continue to implement renewable energy shows that they are making progress to overcome these barriers.

CONCLUSION

Based on the analysis completed in this project, a number of conclusions can be made. The first hypothesis, “Germany’s centralized approach is more effective in the transition to renewable energy,” was found to be true. Additionally, the second hypothesis “Both Germany’s and the United States’ renewable energy transitions are sustainable,” was found to still be in question.

While Germany’s centralized approach was found to be more effective, it is not to say that the United States’ decentralized approach has not been effective. In fact, the complex indicator, “Effectiveness Indicator,” indicated both Germany’s and the United States’ methods to be effective. Additionally, this paper used methodologies that may produce different results when different factors are considered. This conclusion was made solely based on the analysis completed for this project. Qualitative assessments may change this conclusion.

It should be noted that while Germany’s centralized approach is effective for their renewable energy transition, this approach may not be the correct approach for the United States to take. The United States’ decentralized approach, while less effective than Germany’s centralized approach, was still deemed to be effective. Perhaps the United States is already operating at maximum effectiveness. Policies from Germany cannot just be implanted into the United States, as the two countries have differing political, social, and economic conditions.

It should also be noted that without Germany's ambitious transition to renewable energy, the United States would not have been able to effectively transition at all with a decentralized approach. The United States' transition is mainly led by prevailing market forces, specifically due to first movers like Germany investing in the technology when it was not cost effective. Without Germany's centralized approach, it is very possible that the United States' decentralized transition would not have occurred.

While this project concluded that renewable energy development is currently unsustainable, this is not to say that it will never be sustainable. The SIP identified what has to be accomplished for sustainability. The first step to overcoming resistance is to identify the key factors resisting change. Because these key factors were identified, efforts can now be made to reduce the effects of these factors. After these factors are addressed, it is likely that renewable energy development will be sustainable.

APPENDICES

Appendix A ("Energy Consumed" Data Groupings)

Grouping	Germany's Data	United States' Data
Mineral Oil	Mineral Oil	N/A
Coal	Hard Coal + Brown Coal	Coal
Natural & Petroleum Gas	Natural, Petroleum Gas	Natural Gas + Petroleum Gas
Nuclear Energy	Nuclear Energy	Nuclear Electric Power
Water, Wind, & Solar	Water & Wind was renamed (solar is included in Germany's number)	Hydroelectric + Solar + Wind
Other Renewable	Other Renewable	Geothermal + Biomass
Other	Foreign Trade Balance Electricity + Other	N/A

Appendix B (“Energy Consumed” Raw Data – Germany)

Bundesministerium für Wirtschaft und Energie

Primärenergieverbrauch nach Energieträgern

Deutschland

Energiedaten
Tabelle 4
letzte Änderung: 20.12.2017

in Petajoule (PJ)

Energieträger	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Mineralöl	5,217	5,525	5,612	5,731	5,681	5,689	5,808	5,753	5,775	5,599	5,499	5,577	5,381	5,286
Steinkohle	2,306	2,330	2,196	2,139	2,140	2,060	2,090	2,065	2,059	1,967	2,021	1,949	1,927	2,010
Braunkohle	3,201	2,507	2,176	1,983	1,861	1,734	1,688	1,595	1,514	1,473	1,550	1,633	1,663	1,639
Erdgas, Erdölgas	2,293	2,409	2,382	2,520	2,567	2,799	3,132	2,992	3,019	3,010	2,985	3,148	3,143	3,181
Kernenergie	1,668	1,609	1,733	1,675	1,650	1,682	1,764	1,859	1,764	1,855	1,851	1,868	1,798	1,801
Wasser- und Windkraft [1) 3)]	58	53	62	64	67	83	73	77	80	91	127	124	145	132
andere Erneuerbare [2)]	139	145	145	164	186	191	197	267	299	312	290	308	310	429
Außenhandelssaldo Strom	3	-2	-19	3	8	17	-19	-8	-2	4	11	10	2	-29
Sonstige	22	35	32	30	25	13	13	14	12	12	68	62	57	151
Gesamtverbrauch	**14,905**	**14,610**	**14,319**	**14,309**	**14,185**	**14,269**	**14,746**	**14,614**	**14,521**	**14,323**	**14,402**	**14,679**	**14,427**	**14,600**

Energieträger	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Mineralöl	5,214	5,166	5,121	4,626	4,904	4,635	4,684	4,525	4,527	4,628	4,493	4,491	4,567	4,675
Steinkohle	1,909	1,808	1,964	2,017	1,800	1,496	1,714	1,715	1,725	1,840	1,759	1,729	1,656	1,489
Braunkohle	1,648	1,596	1,576	1,613	1,554	1,507	1,512	1,564	1,645	1,629	1,574	1,565	1,519	1,510
Erdgas, Erdölgas	3,198	3,250	3,312	3,191	3,222	3,039	3,171	2,911	2,920	3,059	2,660	2,770	3,025	3,200
Kernenergie	1,822	1,779	1,826	1,533	1,623	1,472	1,533	1,178	1,085	1,061	1,060	1,001	923	828
Wasser- und Windkraft [1) 3)]	166	173	191	230	236	231	254	309	356	381	407	493	490	451
andere Erneuerbare [2)]	485	596	748	886	911	970	1,160	1,153	1,029	1,118	1,112	1,151	1,207	1,322
Außenhandelssaldo Strom	-26	-31	-71	-69	-81	-52	-64	-23	-83	-116	-122	-174	-182	-194
Sonstige	176	222	171	169	210	231	254	267	244	222	237	231	246	244
Gesamtverbrauch	**14,591**	**14,558**	**14,837**	**14,197**	**14,380**	**13,531**	**14,217**	**13,599**	**13,447**	**13,822**	**13,180**	**13,258**	**13,451.340**	**13,525.0**

Appendix C ("Energy Consumed" Raw Data – United States)

U.S. Energy Information Administration

March 2018 Monthly Energy Review

Note: Information about data precision.

Release Date: March 27, 2018
Next Update: April 25, 2018

Table 1.3 Primary Energy Consumption by Source

Annual Total	Coal Consumption (Quadrillion Btu)	Natural Gas Consumption (Excluding Supplemental Gaseous Fuels) (Quadrillion Btu)	Petroleum Consumption (Excluding Biofuels) (Quadrillion Btu)	Total Fossil Fuels Consumption (Quadrillion Btu)	Nuclear Electric Power Consumption (Quadrillion Btu)	Hydroelectric Power Consumption (Quadrillion Btu)	Geothermal Energy Consumption (Quadrillion Btu)	Solar Energy Consumption (Quadrillion Btu)	Wind Energy Consumption (Quadrillion Btu)	Biomass Energy Consumption (Quadrillion Btu)	Total Renewable Energy Consumption (Quadrillion Btu)	Total Primary Energy Consumption (Quadrillion Btu)
1990	19.172635	19.603167	33.551623	72.332203	6.10435	3.046391	0.170747	0.058756	0.029007	2.735112	6.040013	84.484454
1991	18.99167	20.032958	32.846032	71.880348	6.422132	3.015943	0.177626	0.06161	0.030796	2.781797	6.067773	84.437218
1992	19.122471	20.713632	33.524957	73.395686	6.479206	2.617436	0.178699	0.062867	0.029863	2.931678	5.820543	85.782168
1993	19.835148	21.228902	33.68724	74.7784	6.410499	2.891613	0.185673	0.065175	0.030987	2.908172	6.08162	87.365429
1994	19.909463	21.728067	34.557545	76.253403	6.693877	2.683457	0.173464	0.06711	0.03556	3.027534	5.987125	89.087342
1995	20.088727	22.671139	34.441046	77.261973	7.075436	3.205307	0.152057	0.068214	0.03263	3.101142	6.55935	91.030614
1996	21.001914	23.084647	35.674967	79.78434	7.086674	3.589656	0.163359	0.069112	0.03344	3.156806	7.012372	94.02053
1997	21.445411	23.222716	36.15848	80.873047	6.596992	3.640458	0.166698	0.068142	0.033581	3.10522	7.014098	94.60034
1998	21.655744	22.830226	36.817372	81.370437	7.067809	3.297054	0.16845	0.067422	0.030853	2.92749	6.491268	95.017738
1999	21.622544	22.909227	37.836036	82.4255	7.610256	3.267575	0.170921	0.066034	0.045894	2.96329	6.513715	96.648394
2000	22.579528	23.823977	38.265934	84.734803	7.862349	2.811116	0.164364	0.063433	0.057057	3.008227	6.104198	98.816549
2001	21.914268	22.772558	38.189656	82.905742	8.028853	2.241858	0.164461	0.06163	0.069617	2.622356	5.159922	96.169673
2002	21.903989	23.510081	38.225566	83.700394	8.145429	2.689017	0.171164	0.059928	0.105334	2.700621	5.726064	97.643483
2003	22.320928	22.830642	38.789798	83.991883	7.959622	2.792539	0.173445	0.058372	0.113273	2.806471	5.9441	97.91751
2004	22.466195	22.923061	40.226667	85.753685	8.222774	2.688468	0.178147	0.058302	0.141664	3.008073	6.074653	100.089709
2005	22.796543	22.565364	40.302834	85.708932	8.16081	2.702942	0.180703	0.057783	0.178088	3.11393	6.233446	100.187732
2006	22.44716	22.238738	39.823636	84.570321	8.214626	2.869035	0.1812	0.060596	0.263738	3.26214	6.636709	99.484506
2007	22.749466	23.662759	39.48925	85.926667	8.458589	2.446389	0.185774	0.065397	0.340503	3.484824	6.522886	101.014775
2008	22.387437	23.842953	36.90682	83.177983	8.426491	2.511108	0.192433	0.073848	0.545548	3.851392	7.17433	98.89079
2009	19.691205	23.41594	34.95905	78.042385	8.35522	2.668824	0.200185	0.0777	0.721129	3.93603	7.603868	94.11766
2010	20.833968	24.574754	35.488347	80.890897	8.434433	2.538541	0.207979	0.090478	0.923427	4.405248	8.165673	97.579636
2011	19.657784	24.954539	34.828344	79.45177	8.268698	3.102852	0.212311	0.110891	1.167636	4.534162	9.127852	96.975422
2012	17.378234	26.088582	34.011568	77.482367	8.061822	2.628702	0.211592	0.157023	1.340059	4.491974	8.829351	94.534795
2013	18.038633	26.805134	34.619323	79.445669	8.244433	2.562382	0.214006	0.225035	1.601359	4.850217	9.453	97.340574
2014	17.997632	27.382833	34.874481	80.233386	8.337559	2.466577	0.21449	0.336793	1.727542	4.992212	9.737613	98.490117
2015	15.54887	28.191095	35.605421	79.327605	8.336886	2.321177	0.211836	0.426463	1.777306	4.897906	9.634688	97.526659
2016	14.225905	28.445052	36.016958	78.668776	8.426753	2.472442	0.209604	0.5697	2.095595	4.913246	10.260587	97.561762
2017	13.972867	28.033197	36.240973	78.218504	8.418968	2.770011	0.210991	0.77536	2.347276	4.913249	11.016886	97.827264

Appendix D ("Energy Consumed" Processed Data)

Germany's Primary Energy Consumption by Energy Source																												
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Fuels	Primary Energy Consumption in Million Kilowatt Hours																											
Mineral Oil	1,449,145	1,534,641	1,558,873	1,592,059	1,578,043	1,580,257	1,613,417	1,598,087	1,604,213	1,555,149	1,527,379	1,549,167	1,494,788	1,468,419	1,448,359	1,434,942	1,422,424	1,284,976	1,362,089	1,287,582	1,300,992	1,256,813	1,257,374	1,285,528	1,247,992	1,247,639	1,268,583	1,298,611
Coal	1,529,691	1,343,595	1,214,475	1,144,802	1,111,428	1,053,916	1,049,379	1,016,795	992,491	955,563	992,077	994,913	997,126	1,013,597	988,084	945,366	983,293	1,008,287	931,808	834,292	896,172	910,791	936,074	963,399	925,895	915,056	882,066	833,056
Natural & Petroleum Gas	636,883	669,193	661,627	700,113	712,927	777,374	869,910	831,034	838,650	836,191	829,246	874,482	873,128	883,720	888,211	902,810	920,069	886,362	895,006	844,301	880,713	808,607	811,101	849,743	738,950	769,536	840,390	888,889
Nuclear Energy	463,207	446,849	481,398	465,246	458,374	467,192	490,004	516,400	490,104	515,411	514,208	518,960	499,478	500,178	506,237	494,054	507,136	425,854	450,835	408,882	425,925	327,183	301,392	294,818	294,329	278,138	256,466	230,000
Water, Wind, & Solar	16,074	14,652	17,317	17,676	18,506	23,121	20,357	21,519	22,199	25,332	35,241	34,463	40,406	36,716	45,976	48,092	52,972	63,957	65,440	64,276	70,432	85,896	98,805	105,716	113,001	136,910	136,130	125,278
Other Renewable	38,488	40,163	40,235	45,612	51,703	53,188	54,592	74,162	83,126	86,719	80,474	85,596	86,115	119,071	134,615	165,624	207,740	246,191	253,178	269,344	322,122	320,356	285,864	310,577	308,816	319,697	335,145	367,222
Other	6,855	9,177	3,702	9,220	9,365	8,551	-1,565	1,427	2,707	4,323	21,882	19,939	16,591	33,876	41,670	53,100	27,698	27,949	36,001	49,896	52,743	67,948	44,684	29,555	32,014	15,842	17,704	13,889
Total	**4,140,344**	**4,058,270**	**3,977,627**	**3,974,728**	**3,940,347**	**3,963,599**	**4,096,094**	**4,059,424**	**4,033,491**	**3,978,688**	**4,000,507**	**4,077,521**	**4,007,631**	**4,055,577**	**4,053,150**	**4,043,988**	**4,121,332**	**3,943,576**	**3,994,357**	**3,758,574**	**3,949,099**	**3,777,593**	**3,735,294**	**3,839,336**	**3,660,996**	**3,682,818**	**3,736,483**	**3,756,944**

United States' Primary Energy Consumption by Energy Source																												
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Fuels	Primary Energy Consumption in Million Kilowatt Hours																											
Mineral Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coal	5,618,943	5,565,908	5,604,242	5,813,107	5,834,886	5,887,423	6,155,052	6,285,028	6,346,671	6,336,941	6,617,405	6,422,436	6,419,424	6,541,617	6,584,190	6,681,006	6,578,612	6,667,209	6,561,109	5,770,921	6,105,832	5,761,126	5,093,056	5,286,600	5,274,584	4,556,923	4,169,200	4,095,042
Natural & Petroleum Gas	15,578,127	15,497,298	15,895,758	16,094,329	16,495,681	16,737,925	17,220,739	17,402,906	17,480,981	17,802,675	18,196,752	17,866,257	18,092,928	18,059,164	18,507,354	18,424,846	18,188,682	18,508,022	17,803,997	17,108,017	17,602,753	17,520,629	17,613,611	18,001,727	18,245,813	18,696,909	18,891,946	18,836,895
Nuclear Energy	1,789,008	1,882,141	1,898,867	1,878,731	1,961,781	2,073,605	2,076,899	1,933,387	2,071,370	2,230,345	2,304,226	2,353,024	2,387,189	2,332,734	2,409,857	2,391,697	2,407,469	2,478,967	2,469,560	2,448,673	2,471,888	2,423,316	2,362,686	2,416,204	2,443,497	2,443,300	2,469,637	2,467,355
Water, Wind, & Solar	918,530	910,967	794,271	875,630	816,533	968,937	1,082,079	1,096,725	995,072	990,434	859,169	695,488	836,506	868,716	846,516	861,281	935,884	835,923	917,460	1,016,269	1,041,119	1,284,055	1,209,148	1,286,223	1,327,879	1,326,130	1,505,722	1,726,964
Other Renewable	851,623	867,321	911,561	906,716	938,120	953,418	973,044	958,904	907,330	918,546	929,794	816,735	841,637	873,327	933,789	965,561	1,009,143	1,075,746	1,185,128	1,212,205	1,352,003	1,391,054	1,378,479	1,484,177	1,526,651	1,499,365	1,507,677	1,501,766
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	**24,759,943**	**24,746,100**	**25,140,266**	**25,604,274**	**26,108,916**	**26,678,433**	**27,554,691**	**27,724,616**	**27,846,943**	**28,324,841**	**28,960,265**	**28,184,542**	**28,616,473**	**28,696,783**	**29,333,391**	**29,362,119**	**29,156,024**	**29,604,501**	**28,982,023**	**27,583,157**	**28,597,762**	**28,420,684**	**27,705,407**	**28,527,699**	**28,865,315**	**28,584,084**	**28,598,842**	**28,670,334**

Germany's Primary Energy Consumption by Energy Source																												
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Fuels	Primary Energy Consumption in Kilowatt Hours Per Capita																											
Mineral Oil	18,244	19,180	19,335	19,617	19,377	19,347	19,696	19,481	19,552	18,942	18,579	18,812	18,121	17,792	17,552	17,400	17,267	15,620	16,589	15,721	15,909	15,656	15,634	15,940	15,411	15,273	15,346	15,815
Coal	19,258	16,792	15,063	14,106	13,647	12,903	12,811	12,395	12,097	11,639	12,067	12,082	12,088	12,281	11,974	11,463	11,937	12,256	11,348	10,186	10,959	11,346	11,639	11,946	11,433	11,202	10,670	10,145
Natural & Petroleum Gas	8,018	8,363	8,206	8,627	8,754	9,518	10,620	10,130	10,222	10,185	10,087	10,619	10,585	10,707	10,764	10,947	11,169	10,774	10,900	10,309	10,770	10,073	10,085	10,537	9,125	9,421	10,166	10,825
Nuclear Energy	5,831	5,585	5,971	5,733	5,628	5,720	5,982	6,295	5,973	6,278	6,255	6,302	6,055	6,060	6,135	5,991	6,156	5,177	5,491	4,992	5,208	4,076	3,747	3,656	3,634	3,405	3,102	2,801
Water, Wind, & Solar	202	183	215	218	227	283	249	262	271	309	429	418	490	445	557	583	643	777	797	785	861	1,070	1,229	1,311	1,395	1,676	1,647	1,526
Other Renewable	485	502	499	562	635	651	666	904	1,013	1,056	979	1,039	1,044	1,443	1,631	2,008	2,522	2,993	3,083	3,289	3,939	3,991	3,554	3,851	3,813	3,914	4,054	4,472
Other	86	115	46	114	115	105	-19	17	33	53	266	242	201	410	505	644	336	340	438	609	645	846	556	366	395	194	214	169
Total	**52,124**	**50,720**	**49,335**	**48,976**	**48,384**	**48,527**	**50,004**	**49,484**	**49,161**	**48,461**	**48,661**	**49,515**	**48,584**	**49,138**	**49,119**	**49,036**	**50,030**	**47,937**	**48,646**	**45,891**	**48,291**	**47,058**	**46,444**	**47,607**	**45,207**	**45,085**	**45,199**	**45,753**

United States' Primary Energy Consumption by Energy Source																												
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Fuels	Primary Energy Consumption in Kilowatt Hours Per Capita																											
Mineral Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coal	22,510	22,001	21,848	22,365	22,175	22,110	22,848	23,051	23,007	22,710	23,452	22,537	22,319	22,549	22,487	22,608	22,048	22,133	21,576	18,812	19,738	18,485	16,220	16,719	16,557	14,201	12,903	12,572
Natural & Petroleum Gas	62,407	61,259	61,968	61,921	62,691	62,859	63,924	63,827	63,370	63,800	64,490	62,695	62,905	62,250	63,207	62,348	60,958	61,441	58,548	55,768	56,903	56,217	56,095	56,931	57,275	58,265	58,466	57,832
Nuclear Energy	7,167	7,440	7,403	7,228	7,456	7,787	7,710	7,091	7,509	7,993	8,166	8,257	8,300	8,041	8,230	8,093	8,068	8,229	8,121	7,982	7,991	7,775	7,525	7,641	7,670	7,614	7,643	7,575
Water, Wind, & Solar	3,680	3,601	3,096	3,369	3,103	3,639	4,017	4,022	3,607	3,549	3,045	2,441	2,908	2,994	2,891	2,914	3,137	2,775	3,017	3,313	3,366	4,120	3,851	4,068	4,168	4,133	4,660	5,302
Other Renewable	3,412	3,428	3,554	3,488	3,565	3,581	3,612	3,517	3,289	3,292	3,295	2,866	2,926	3,010	3,189	3,267	3,382	3,571	3,897	3,951	4,370	4,463	4,390	4,694	4,792	4,672	4,666	4,611
Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	**99,189**	**97,818**	**98,007**	**98,509**	**99,226**	**100,190**	**102,284**	**101,683**	**100,948**	**101,508**	**102,637**	**98,904**	**99,492**	**98,918**	**100,181**	**99,359**	**97,714**	**98,278**	**95,306**	**89,914**	**92,445**	**91,190**	**88,234**	**90,219**	**90,611**	**89,076**	**88,506**	**88,022**

Appendix E ("Effectiveness Indicator" Raw Data – Germany)

Figure 6: Electricity generation from renewable energy sources

	Hydropower[1]	Onshore wind energy	Offshore wind energy	Biomass[2]	Photovoltaics	Geothermal energy	Total gross electricity generation	Share of gross electricity consumption
			(GWh)[3]				(GWh)[3]	(%)
1990	17,426	71	–	1,435	1	–	18,933	3.4
2000	21,732	9,513	–	4,731	60	–	36,036	6.2
2005	19,638	27,229	–	14,354	1,282	0.2	62,503	10.2
2006	20,008	30,710	–	18,700	2,220	0.4	71,638	11.6
2007	21,170	39,713	–	24,363	3,075	0.4	88,321	14.2
2008	20,443	40,574	–	27,792	4,420	18	93,247	15.1
2009	19,031	38,610	38	30,631	6,583	19	94,912	16.3
2010	20,953	37,619	176	33,925	11,729	28	104,430	17.0
2011	17,671	48,314	577	36,891	19,599	19	123,071	20.3
2012	22,091	49,949	732	43,216	26,380	25	142,393	23.5
2013	22,998	50,803	918	45,527	31,010	80	151,336	25.1
2014	19,587	55,908	1,471	48,301	36,056	98	161,421	27.3
2015	18,977	70,922	8,284	50,321	38,726	134	187,364	31.5
2016	20,546	66,324	12,274	50,815	38,095	162	188,216	31.7

1 For pumped-storage power plants, only electricity generation from natural inflow

2 Incl. solid and liquid biomass, biogas incl- biomethane, sewage gas and landfill gas and the biogenic share of waste (biogenic share of waste in waste incineration plants estimated at 50%); also including sewage sludge as of 2010

3 1 GWh = 1 million kWh

Sources: Federal Ministry for Economic Affairs and Energy (BMWi) based on data from AGEE-Stat; ZSW; AGEB [1], [2], [4], [5]; BDEW; BMWi; BNetzA [6]; StBA; DBFZ; ÜNB [7]; ITAD, UBA [21], some figures provisional

Appendix F ("Effectiveness Indicator" Raw Data – United States)

U.S. Energy Information Administration		
March 2018 Monthly Energy Review		
Note: Information about data precision.		
Release Date: March 27, 2018		
Next Update: April 25, 2018		
Table 10.2c Renewable Energy Consumption: Electric Power Sector		
Annual Total	**Solar Energy Consumed by the Electric Power S**	**Wind Energy Consumed by the Electric Power Sector**
	(Trillion Btu)	**(Trillion Btu)**
2009	8.697	721.127
2010	11.762	923.271
2011	16.782	1167.094
2012	39.625	1339.365
2013	83.24	1600.424
2014	164.562	1726.026
2015	227.901	1775.705
2016	327.712	2093.728
2017	483.076	2345.292

Appendix G ("Effectiveness Indicator" Processed Data)

	Solar (GWh)		Wind (GWh)		Solar & Wind (GWh)	
Year	Germany	US	Germany	US	Germany	US
2009	6,583	2,549	38,648	211,341	45,231	213,890
2010	11,729	3,447	37,795	270,584	49,524	274,031
2011	19,599	4,918	48,891	342,041	68,490	346,960
2012	26,380	11,613	50,681	392,529	77,061	404,142
2013	31,010	24,395	51,721	469,038	82,731	493,433
2014	36,056	48,228	57,379	505,848	93,435	554,077
2015	38,726	66,791	79,206	520,408	117,932	587,199
2016	38,095	96,043	78,598	613,611	118,022	709,654
2017	39,895	141,576	106,614	687,337	146,509	828,913

	Effectiveness Indicator Results -Solar		Effectiveness Indicator Results -Wind		Effectiveness Indicator Results - Solar & Wind	
Year	Germany	US	Germany	US	Germany	US
2010	25.50%	0.07%	-3.58%	7.46%	9.76%	2.90%
2011	52.35%	0.12%	45.01%	9.72%	47.79%	3.62%
2012	94.65%	0.54%	13.20%	7.61%	41.37%	2.95%
2013	N/A Realisable potential was realized	1.05%	8.84%	12.47%	46.67%	4.74%
2014		1.97%	52.75%	6.86%	N/A Realisable potential was realized	3.38%
2015		1.56%	N/A Realisable potential was realized	2.91%		1.91%
2016		2.51%		19.20%		7.21%
2017		4.00%		18.80%		7.57%
Average	**57.50%**	**1.48%**	**23.24%**	**10.63%**	**36.40%**	**4.29%**

2030 Realisable Potential Calculation	
US	
Gross Electrical Demand (GWh)	11,430,000
Solar & Wind Goal (20%)	2,286,000
Solar (54%)	1,234,440
Wind (44%)	1,005,840
Germany	
Gross Electrical Demand (GWh)	162,200
Solar & Wind Goal (55%)	89,210
Solar (30%)	26,763
Wind (70%)	62,447

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