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Précis

The current sources of energy that the United States uses to produce electricity are costly, extremely damaging to the environment, and cause us to rely on other countries for our energy needs. The Obama Administration has begun working on replacing coal and oil with cleaner sources of energy. Over the last decade, alternative energy sources have been slowly gaining popularity as the American public learns more about climate change. However, the U.S. government will not use renewable energy as a complete substitute for fossil fuels in the immediate future because of their higher market price. The world is struggling to bear the damages caused by the production of electricity, and finding a cheap and clean energy source, not only for the United States but for the rest of the world, will become increasingly important as the BRIC countries grow in population, production, and exports. My paper will analyze current energy sources for electricity production and attempt to find better alternatives than the current energy distribution.

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Introduction and Contributions

The Unites States currently uses coal as its main source of producing electricity. Natural gas, nuclear, and renewable energy sources are also used. The Obama Administration has plans to substitute coal with different types of energy sources, and there is debate among scientists, politicians, and citizens about which energy source to use.

My thesis has three purposes. The first purpose is to find the 2011 market price per kWh of all main sources of energy used to produce electricity in the United States. The second purpose is to calculate the externality costs and total cost for each of these sources of energy in terms of $ per kWh, and then evaluate the feasibility of both using only sources with the lowest externality costs to meet the electricity needs of the United States, as well the energy sources outlined in the Obama Energy Plan. The third purpose is to compare the market prices, externality costs, and total costs of producing electricity for the United States using only sources of energy with the lowest externality costs against those sources of energy the Obama Energy Plan will lead us to by 2030. The findings of this study will be in the interest of U.S. electricity production companies and politicians. It will help evaluate and compare energy sources in a more thorough way than the current methodology.

Reviewing the Literature and Current Events

Through my research I found that price, and political and legal factors affect the use of different sources of energy the most. The lower the market price and the more favorable regulation and support from the government, the more widely used an energy source is. Researchers at Kobe University in Japan analyzed 11 years of data to conclude that government

policy had a clear effect on energy adoption (Zhang, 2011). Additionally, a lower market price prior to subsidization gives the government an incentive to support that energy source over others. Government subsidies and other government-funded incentives are hidden costs that are not added onto the market price, though taxpayers pay for these hidden costs. Externality costs are also hidden costs, however, nobody pays for the majority of them and they are also not accounted for in the market price. Thus, I will be including the cost of externalities into my total cost calculations, which these energy sources produce as a byproduct of being converted into electricity. Externality costs are very important to consider when talking about energy and specifically renewable energy, since lowering carbon emissions and other pollutants are a common reason for making the switch.

Externalities are the side effects of economic activity, and often do not form part of the prices paid by producers or consumers directly involved. When externalities are not included in prices, they can create large distortions in the market by encouraging activities that are costly to society, even when private benefits are substantial (Buonamici and Masoni, 2012). Calculating the economic value of externalities is complex because of the numerous variables that need to be taken into account, but a study done by the European Commission states that total external costs attributable to energy sector are relatively high – around €12 billion in total for the Czech Republic, Hungary and Poland, representing about 3.7 % of their GDP (Bickel and Friedrich, 2005). External costs for electricity generation in power plants depend on the technology installed and the energy source used, though presently, the type of energy source used has much more of an impact than the technology.

To calculate externality costs, I used a source called ExternE: a series of reports created by the European Commission which attempt to measure the damages to society through the

usage of different sources of energy which are not paid for by the main creators, and translates these damages into a monetary value. Three main sources of damage are analyzed in the reports: impacts on the environment such as releasing substances (e.g. fine particles) or energy (noise, radiation, heat) into the air, soil and water, impacts related to climate change, and both public and occupational accident risks associated with obtaining materials for and generating electricity. Airborne pollutants, the consequences of transportation, sound propagation, air, water, and soil contamination, premature mortality, morbidity, impacts on building materials and crops, mental trauma, evacuation and resettlement, bans on consumption of food, land contamination, economic losses, and clean up and repair costs were all studied in these reports. The ExternE reports were the first of their kind, and they are still one of the best resources to use when talking about externality costs, as most similar reports heavily base their calculations and methodology on what the ExternE reports already did. The last update to these unique reports was in 2005, which does not include several oil spills and the recent meltdown of the nuclear reactors in Japan. However, because of the complexity of calculating this data, I will continue to use the information provided in the ExternE reports, albeit with some minor changes.

Most authors compare energy sources solely based on their market price, and there is an abundance of literature on this topic. As stated earlier, this method of comparison can give fossil fuels a misleading advantage over renewable energy because externality costs are not taken into account. There are limited literary resources for calculating externality costs, and this subject would greatly benefit from more scholarly contributions. The current externality costs literature for the United States is not as inclusive as the European ExternE reports, and does not include several energy sources that are used in the United States. For this reason I will be using the

ExternE reports in my paper. There is a complete deficiency in literature about the total costs of energy, which is a gap my paper intends to fill.

To help compare the total costs of future energy sources, I will be using Obama's Energy Plan as a source for estimating the future energy distribution of the United States. The Obama Energy Plan can be used as a likely predictor of what the distribution of energy sources will be in the future of the United States, since political and legal factors affect the price of energy the most. The plan gave short-term relief for Americans suffering the consequences of regulatory loopholes in the commodity futures market which enabled speculative commerce and contributed to high petroleum prices. This was achieved through tax rebates to help pay for gas, closing loopholes, and releasing oil from the strategic petroleum reserve to increase supply and reduce gasoline prices. The plan also gives long-term solutions for eradicating America's foreign oil dependence, boosting economic growth, and reducing greenhouse gas emissions. This will be accomplished by investing $150 billion in the sustainable energy industry over the next decade, trying to pass the Cross-State Air Pollution Rule cap and trade system, establishing federal renewable portfolio standards for power plants, improving the fuel efficiency of vehicles, diversifying America's energy sources with biofuels, clean coal, and nuclear energy, beginning to replace coal with natural gas, and investing in smarter electricity grids.

Aside from literature on the costs of energy, renewable energy sources have a deficiency in research and technological advances that fossil fuels have been able to cultivate since they have only recently become a viable substitute for traditional energy sources. The current research on fossil fuels focuses mainly around finding new sources and extraction techniques, as well as creating technologies that will use these energy sources more efficiently and cleanly. Renewable

energy research focuses on reducing production costs, testing how different materials affect their energy efficiency, as well as finding new ways to store energy.

Hypotheses

I expect that the market prices of coal, natural gas, and nuclear energy will have the lowest market price per kWh out of all the main sources of energy used to produce electricity in the United States based on their popularity. I predict that wind and solar energy will have the lowest externality costs. I expect that natural gas will have the lowest total cost, based on its heavy advocacy in Obama's Energy Plan. Lastly, I hypothesize that the distribution of energy sources in Obama's Energy Plan will have lower market prices, higher externality costs, and lower total costs than an energy plan made up of sources of energy with the lowest externality costs.

Calculating the cost of energy

In order to find what sources of energy my paper will focus on, it is first necessary for me to market price of each energy source. To do this, I will be calculating the cost per kilowatt-hour (kWh) for every major energy source used in the United States based on Morgan (2010). Jason Morgan, a corporate finance and accounting professional, along with Jack Gamble, an engineer in the nuclear energy industry, advocated for switching to nuclear energy based on its low market price per kWh in order to solve the future of the world's energy crisis. Although his calculations are now outdated, his method of finding the market price per kWh is more accurate than the Energy Information Administration's and other similar sources, because he includes most of the costs and limiting factors associated with generating electricity from specific power plants.

These costs and limitations include the megawatts the power plant is capable of producing, the estimated construction cost, the power plant's useful life and capacity factor, operations and maintenance costs, fuel costs, and decommissioning costs.

In order to obtain accurate results for my own kilowatt-hour calculations, I used information from power plants built in 2008 or later, most being built after 2010 or are currently under construction. These power plants had up-to-date technology that did not significantly vary from those that are now available in April 2012. In my calculations, some energy sources have similar data for multiple power plants, but with differing construction costs or capacity factors. This is to account for variation in geography and expected costs of construction. Market price calculations for different energy sources can be found in Figure 1, and an in-depth explanation of how these values were calculated is provided below:

Power plants are conventionally measured in the number of megawatts they are able to continuously produce, so this is the starting point for each calculation. From there, I researched the estimated construction cost and useful life of each power plant based on information reported by the utility company or through newspaper articles. I selected the power plants used in my calculations based on how recently they were built, the availability of all relevant information needed to compute calculations, and how many megawatts they were able to produce (higher megawatts means a bigger power plant, which is usually more cost efficient). After using this information, I needed to find the capacity factor of each power plant, which is a measure of the performance of a power source over time as a percentage of its full power potential. For example, a power plant with a 50% capacity factor would operate at 100% power, 50% of the time. Alternatively, a power plant with a capacity factor of 50% could also operate at 50% power, 100% of the time. The capacity factor is different for each power plant, depending of

what kind of technology is used to generate the electricity, and the source of energy. For example, solar energy would have a lower capacity factor than some other sources of energy because the panels are only able to produce electricity half the day while the sun is out.

There are various methods of calculating the total kWh produced over a power plant's useful life, but they only vary slightly by adding more constraints that limit total electricity production (Schleede, 2003). I used a base formula that Morgan also uses in his calculations, which includes the most important constraint, the capacity factor:

(8760 hours in a year * the capacity factor of each power plant) * (years the power plant would be in use) * (MW * 1000).

The first part of this formula calculates how many hours in a year the power plant is in service, which is then multiplied by the power plant's useful life in years, which is then multiplied by the kilowatts the power plant is capable of producing (one megawatt is equal to 1000 kilowatts, and one kWh is simply the number of kilowatts multiplied by the number of hours in use).

Using the results found for the total kWh for a power plant's useful life, I was then able to find the construction cost per kWh: (Estimated construction cost/total kWh produced over useful life). Production costs per kWh and decommissioning costs per kWh were either provided in the power plant data, or provided by the Ventyx Velocity Suite (Nuclear Energy Institute, 2012).

Thus, the market price for each energy source was calculated by: Construction cost per kWh + production costs per kWh + decommissioning costs per kWh. Throughout my paper, market price will refer to this calculation, which is the cost per kWh not including externalities

of producing electricity. Petroleum, wind, and solar have the highest market prices, while hydropower and nuclear have the lowest market prices.

After calculating the market price per kWh of energy sources, I then researched externality costs associated with different types of energy using ExternE and added them to the prices of energy in order to find the total cost of energy. Since the report was created by the European Commission and much of the data is taken from countries in the European Union, the cost of externalities was given in Euros. I used the exchange rate of $1.20268 USD/Euro, which was the exchange rate in October 2005, when the ExternE reports were last updated. To convert Euros into dollars, I multiplied the Euro externality cost by the exchange rate (X-Rates, 2012). For the coal externalities, I averaged the externality costs of lignite and anthracite.

The final calculation of total cost per kWh = Market Price + Externalities cost per kWh. I then averaged the market prices, externality costs, and total costs of each energy source that had information from more than one power plant, and I will be using these three different averages to compare and evaluate each energy source. I used three power plant samples for coal, one for natural gas, three for nuclear, two for hydroelectric, two for wind, and one for solar.

Figure 1: Calculating cost per kWh, including the cost of externalities, of various energy sources

Utility	**Wisconsin Power & Light**	**Duke Energy**	**AMP-Ohio**	**Northwest Planning Council Center**	**Georgia Power-Southern Co.**	**Georgia Power-Southern Co.**
Type	Coal	Coal	Coal	Natural Gas	Nuclear	Nuclear
MW	300	600	960	597	2,300	2,300
Estimated Construction Cost	$1,200,000,000.00	$3,000,000,000.00	$4,000,000,000.00	$370,737,000.00	$10,000,000,000.00	$14,500,000,000.00
Useful life (years)	40	40	40	30	40	40
Capacity factor	73.6%	73.6%	73.6%	87.0%	91.8%	91.8%
Total kWh produced over useful life	77,368,320,000	154,736,640,000	247,578,624,000	136,495,692,000	739,834,560,000	739,834,560,000
Construction cost per kWh	$0.016	$0.019	$0.016	$0.003	$0.014	$0.020
Production costs per kWh Operations & Maintenance (incl fuel)	$0.0306	$0.0306	$0.0306	$0.0486	$0.0214	$0.0214
Decommissioning costs per kWh (nuclear only)	$0.000	$0.000	$0.000	$0.000	$0.002	$0.002
Market price	**$0.046**	**$0.050**	**$0.047**	**$0.051**	**$0.036**	**$0.042**
Externalities cost per kWh Euro	€ 0.0463	€ 0.0463	€ 0.0463	€ 0.0100	€ 0.0150	€ 0.0150
Externalities cost per kWh $USD	$0.056	$0.056	$0.056	$0.012	$0.018	$0.018
Total cost per kWh	**$0.1018**	**$0.1057**	**$0.1024**	**$0.0633**	**$0.0545**	**$0.0605**

Utility	Georgia Power-Southern Co.	China	Allegheny Energy	-	We Energies	We Energies	Copper Mountain Solar 1
Type	Nuclear	Hydro	Hydro	Petroleum	Wind	Wind	Solar
MW	2,300	22,500	380	-	207	207	48
Estimated Construction Cost	$18,000,000,000.00	$30,000,000,000.00	$1,500,000,000.00	-	$450,000,000.00	$450,000,000.00	$141,000,000.00
Useful life (years)	40	40	40	-	20	30	20
Capacity factor	91.8%	37.0%	42.0%	-	19.6%	19.6%	17.0%
Total kWh produced over useful life	739,834,560,000	2,917,080,000,000	55,923,840,000	-	7,108,214,400	10,662,321,600	1,429,632,000
Construction cost per kWh	$0.024	$0.010	$0.027	-	$0.063	$0.042	$0.099
Production costs per kWh Operations &Maintenance (incl fuel)	$0.0214	$0.0090	$0.0090	$0.1638	$0.0300	$0.0300	$0.0000
Decommissioning costs per kWh (nuclear only)	$0.002	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Market price	**$0.047**	**$0.019**	**$0.036**	**$0.1638**	**$0.093**	**$0.072**	**$0.099**
Externalities cost per kWh Euro	€ 0.0150	€ 0.0048	€ 0.0048	€ 0.0400	€ 0.0010	€ 0.0010	€ 0.0060
Externalities cost per kWh $USD	$0.018	$0.006	$0.006	$0.048	$0.001	$0.001	$0.007
Total cost per kWh	**$0.0653**	**$0.0250**	**$0.0415**	**$0.2119**	**$0.0945**	**$0.0734**	**$0.1058**

Sources used for Figure 1: Content, T., 2008; Schlissel, D., Smith, A., and Wilson, R., 2008; Northwest Power Planning Council, 2002; Pavey, R., 2010; Wikipedia, 2012; McCloskey, S., 2010; Oil-price.net, 2012; Wind Energy News, 2010.

Method used to calculate petroleum kWh:

Because I was not able to find any information on a power plant that uses solely petroleum to generate electricity (because of how expensive it is), or information related to the inclusive costs of construction and production for partially generating electricity from petroleum, I had to calculate the kWh for petroleum slightly differently than for other sources of electric generation.

One gallon of crude oil can produce 34.7-44.5 kWh when burned. A large power plant is about 42% efficient at converting oil to electricity, so the actual electricity generated is about 17 kWh. There are 42 gallons in a barrel, so the effective kWh is approximately 714. The average 2011 crude oil barrel oil price was $103. Thus, for one barrel of oil: $103/714 kWh = $0.144 per kWh + $0.0198 production cost = $0.1638 per kWh market price.

Nuclear externality cost:

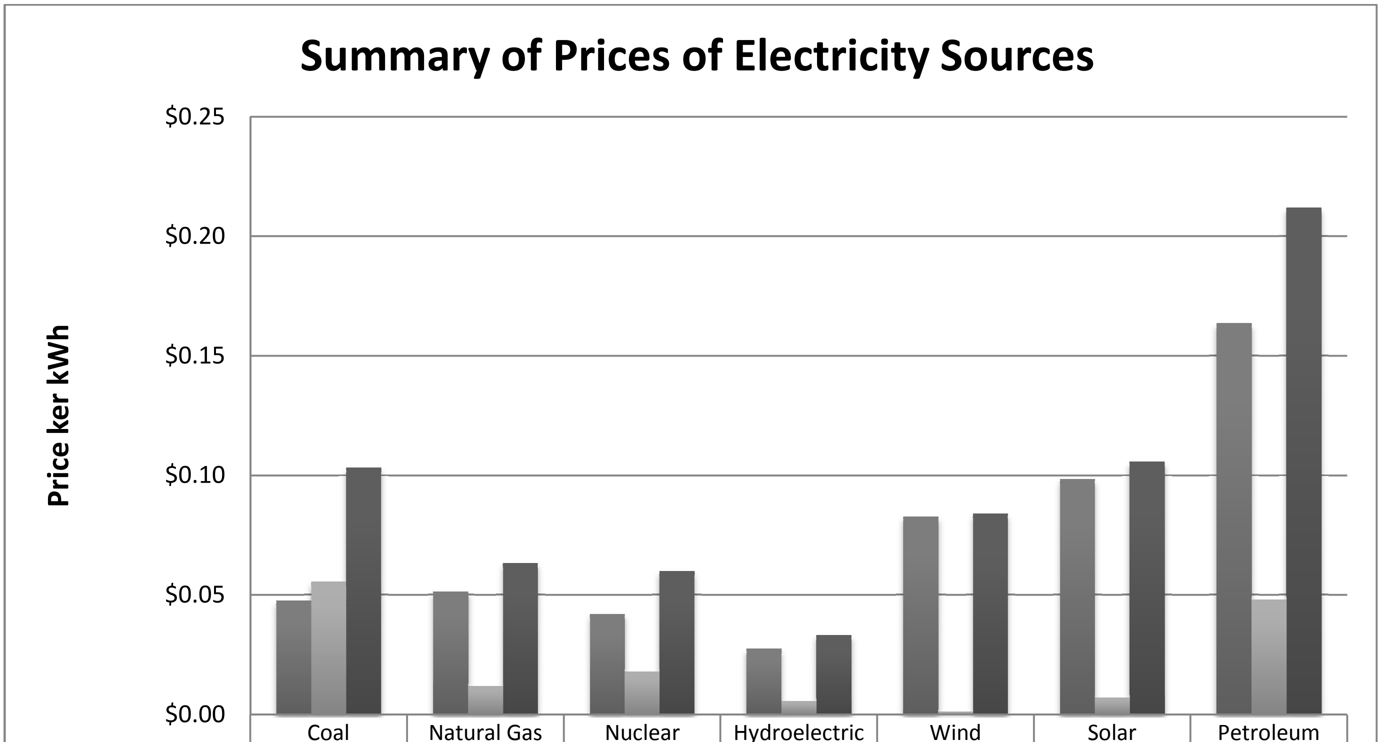
For risks with a very high damage and a low probability, termed 'Damocles' risk, the risk assessment of the public is not proportional to the actual risk. This is often the case with the public's fear of nuclear energy, where there is a small chance of a big accident happening. This is also seen with some people's fear of airplane travel, even though there is a much higher probability of getting into a deadly accident via car transportation. Past attempts to quantify Damocles' risk have not been successful or accepted, so there is currently no accepted method on how to include risk aversion in such an analysis, and it is currently not taken into account for the nuclear externality cost within the ExternE reports (Bickel, Friedrich, 2005, 226). Thus, the externality cost for nuclear may be higher depending on how an individual values this risk. The

current ExternE reports do not account for the recent Fukushima nuclear reactor meltdowns in Japan, since they were last updated in 2005. However, big changes have happened as a result of the incident. As of May 2012, Japan has shut down all 54 of its nuclear power plants which used to provide 30% of all of Japan's electricity. This has caused a trade deficit due to a 74% increase in natural gas imports and a 13% increase in petroleum imports which are being used to generate electricity. Additionally, Japan now has a total debt standing at 235% of its GDP and a budget deficit that is 56% larger than revenues, as well as a recession that is shrinking Japan's economy at a rate of 2.3% annually (Martenson, 2012). Additionally, the accident brought to light the risk associated with nuclear energy which sparked an international anti-nuclear response. Germany pledged to shut down all of its nuclear power plants by 2022, and many countries have begun phasing them out and banning the construction of new reactors. However, the United States government continues to support the development of new nuclear facilities.

To account for this incident, I have increased the externality cost from €0.0039 to €0.015. This had an effect of raising the final cost per kWh including externalities by approximately $0.013 for each nuclear energy calculation. I chose this externality cost for nuclear because it was higher than natural gas, but lower than coal or petroleum. I feel that despite the complicated nature of finding the cost of externalities, this change would be able to at least minimally reflect the nature of the disaster and other potential risks associated with using nuclear energy, however infrequently they may occur.

Figure 2 has a summary of my calculations for each energy source. Petroleum and coal have the highest externality costs. Natural gas has only a marginally higher market price than coal, but has a much lower externality cost, which is a reason why Obama is pushing to replace coal with natural gas. Hydroelectric, wind, and solar have the lowest externality costs, and I will

be assessing the feasibility of using only these sources to meet the electricity needs of the United States. However, since hydroelectric energy is limited by geography and water supply, I will be mainly evaluating wind and solar energy.



	Coal	Natural Gas	Nuclear	Hydroelectric	Wind	Solar	Petroleum
Market Price	$0.05	$0.05	$0.04	$0.03	$0.08	$0.10	$0.16
Externalities cost	$0.06	$0.01	$0.02	$0.01	$0.00	$0.01	$0.05
Total cost	$0.10	$0.06	$0.06	$0.03	$0.08	$0.11	$0.21

Figure 2: Summary of my cost calculations for different energy sources.

An Introduction to Solar and Wind Energy

Photovoltaic cells (solar panels) convert solar radiation into electricity. This has been known for well over fifty years, but until recently, the amounts of electricity generated were very small. Today, solar panels are used to power commercial businesses, warehouses, and even

power plants. Currently, the most popular type of solar panels is a thin film silicon photovoltaic module. These have a power output warranty of ninety percent of the original output power rating during the first ten years, and eighty percent during twenty-five years. After this period, it is recommended that they are replaced.

Solar power has two big advantages over fossil fuels. The first is in the fact that it is renewable; it is never going to run out as long as the sun is still burning. The second is its effect on the environment. While the burning of fossil fuels introduces many harmful pollutants into the atmosphere and contributes to environmental problems like global warming and acid rain, solar energy can be almost completely non-polluting. The primary element solar panels are constructed from is silicon, which is the second most common element on the planet. Thus, there would be little environmental disturbance caused by the creation of solar panels. In fact, solar energy only causes environmental disruption if it is produced and centralized on a gigantic scale in one place, which would cause unpredictable negative environmental effects. If all the solar collectors were placed in one or just a few areas, they would probably have large effects on the local environment, and possibly have large effects on the world environment. Everything from changes in local rain conditions to another Ice Age has been predicted as a result of producing solar energy on this scale. This is due to the change of temperature and humidity near a solar panel; if the energy producing panels are kept non-centralized (such as on residential rooftops), they should not create the same local, mass temperature change that could have such bad effects on the environment.

Of the main types of energy usage, the least suited to solar power is transportation. While large, relatively slow vehicles like ships could power themselves with large onboard solar panels,

small constantly turning vehicles like cars could not. The only possible way a car could be completely solar powered would be through the use of a battery that was charged by solar power at some stationary point and then later loaded into the car. Electric cars that are partially powered by solar energy are available now, but it is unlikely that solar will directly power the world's transportation in the near future.

Wind energy is a free, renewable resource, and no matter how much is used today, there will still be a steady supply in the future. Wind turns the blades of a wind turbine, which spin a shaft which connects to a generator and makes electricity. Wind energy is also a source of clean, non-polluting, electricity. Unlike conventional power plants, wind plants emit no air pollutants or greenhouse gases. Wind turbines generally last around 25 to 30 years, and usually none of the major components need replacement throughout its lifetime. There is concern over the noise produced by the rotor blades of wind turbines, their aesthetic impacts on landscapes, and birds and bats being killed by flying into the rotors. Most of these problems have been resolved or greatly reduced through technological development or by properly siting wind plants.

Both solar and wind energy compete with each other, hydropower, geothermal, biomass and tidal projects, and power generation sources that burn fossil fuels. The most important factors that affect the use of solar and wind energy are:

Technology: Various companies are researching different ways of creating renewable energy. As a result, the more research done on the subject, the cheaper and more efficient these new technologies become. Research and development on solar energy in China has led to technological breakthroughs that have led to massive price reductions and caused some overseas solar panel production companies to fail.

Political and legal: Natural gas and coal companies are threatened by the emerging renewable energy market. However, they still have considerable political influence, which they have amassed over the years of their existence. They could use this influence to sway regulatory decisions in their favor, and could potentially increase competition for alternative energies. Government subsidies, which fund some of the renewable energy research and production, greatly effect whether or not solar panel manufacturers will stay in business. Most solar panel and wind turbine producers focus on marketing in transition markets, which are countries that have the potential of bridging the gap between existing yet still unsubstantial feed-in tariffs and becoming sustainable markets. In simpler terms, countries that are beginning to show interest in solar energy, but aren't quite supporting it yet. In these transition markets, energy subsidies or incentives are minimal but are expected to increase, electricity demand is high, and the country receives abundant solar energy throughout the year. These markets include the United States, China, India, and parts of Europe. In transition markets, the marketing strategy is to advocate for market structures and policies that drive demand for renewable energy. Thus, some renewable energy companies get involved politically in an attempt to obtain subsidies that can enable them to expand their businesses.

Price: The development of the wind and solar industry has been dependent on feed-in tariffs, net metering programs, renewable portfolio standards, tax incentives, loan guarantees, grants, rebates, low interest loans, government subsidies, economic incentives, and other government support programs. They provide the demand visibility required for wind turbine and solar panel manufacturers to reduce costs and increase scale.

Price has the most influence over renewable energy prices, and governments have the highest influence over the prices of energy through subsidization. However, the government can

cause utility companies to use higher prices sources of energy through legislation. For example, the U.S. provides a 30% federal investment tax credit which has been the primary economic driver of solar installations in the United States. Renewable portfolio standards (RPS) require regulated utilities to supply a portion of their electricity in the form of renewable energy. California's RPS goal of 33% by 2020 (highest in the U.S.) and rebate programs are contributing to the demand of wind turbines and solar panels in that state. In Europe, renewable energy targets and feed-in tariffs have contributed to the growth of renewable energy. Thus, the widespread use of a type of energy is directly affected by whether or not a government supports it.

Feasibility of a Renewable Energy Future

Though market price is the public's biggest concern, it is important to know if the United States has the availability of raw materials to build solar and wind technology or the geography to run off solely renewable energy when considering it as an energy source.

Although the scarcity of rare earth materials in absolute terms is unlikely to be a concern, their future supply could be disrupted by technical, environmental, and financial factors (Day, S. 2011). Demand for rare earth materials has risen by over 50 percent in the last decade, and is predicted to rise further. Rare earth elements are used in the production of low-carbon technologies such as wind turbines, but are also used in many everyday items such as LCD and plasma screens, mobile phones, and jet engines. Technical, financial, and environmental challenges of opening new mines could lead to future disruptions in supply. However, these can be remedied through spending in R&D and political dealings. A cause of a recent and ongoing shortage in raw earth materials has been China's massive growth in its wind power sector. Total production of wind turbines in China reached 29 gigawatts (GW) in 2011, which exceeded the

demand of 15 to 18 GW. The accelerated development of the wind power market in China led to excess competition and accelerated the development of a rare-earth metals bubble (which by 2012 has already popped and rare earth prices have begun to lower). This helped incite Beijing's restriction on exports of raw materials and rare earth elements, which caused some foreign companies to pay twice as much as Chinese firms for them. However, it seems that those in the industry were aware that the bubble would eventually pop because a survey by Price Waterhouse Coopers found that 67% of executives in the renewable energy industry felt that they were sufficiently prepared and expressed a lack of concern or low concern about the price of rare earth metals and their effect on the production of renewable energy technologies (Pell, 2011). Alternative and substitute materials are being tested and recycling programs are being put into place to further offset possible supply chain disruptions. Chart 1 shows in black the percentage share of China's contribution to the world's production in rare earth materials. While China produces 95% of the world's rare earth materials, the United States and other countries are beginning to increase rare earth mining, an aftereffect of China's monopoly which has made extraction a more cost-effective solution (UPI, 2012). Thus, it is unlikely that a shortage of rare earth materials will impede renewable energy technology production in the long-term.

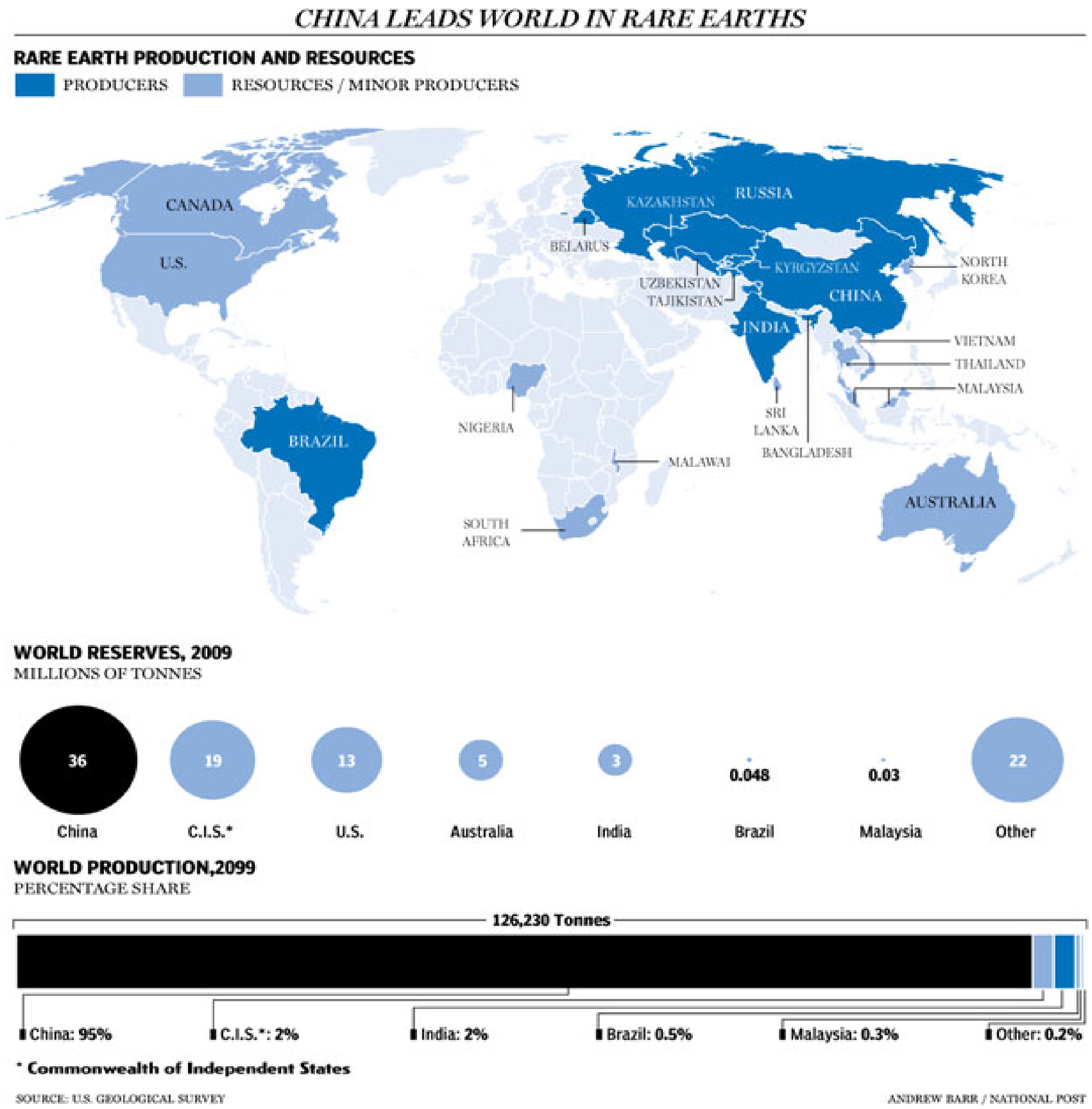


Chart 1: A graphical representation of the major players in rare earths producers.

Source: Moffett and Palmer (2012).

The geography of solar and wind power are directly related to the geography of the climate zones of the earth. Solar power requires direct sunshine throughout the year in order to be cost effective. In the United States, the Southwest is the greatest location for solar power, because it gets the highest amount of daily solar radiation throughout the year. Chart 2 depicts

the possibilities of solar energy in the United States; anything higher than 4.0 (green) is a good place to use solar panels.

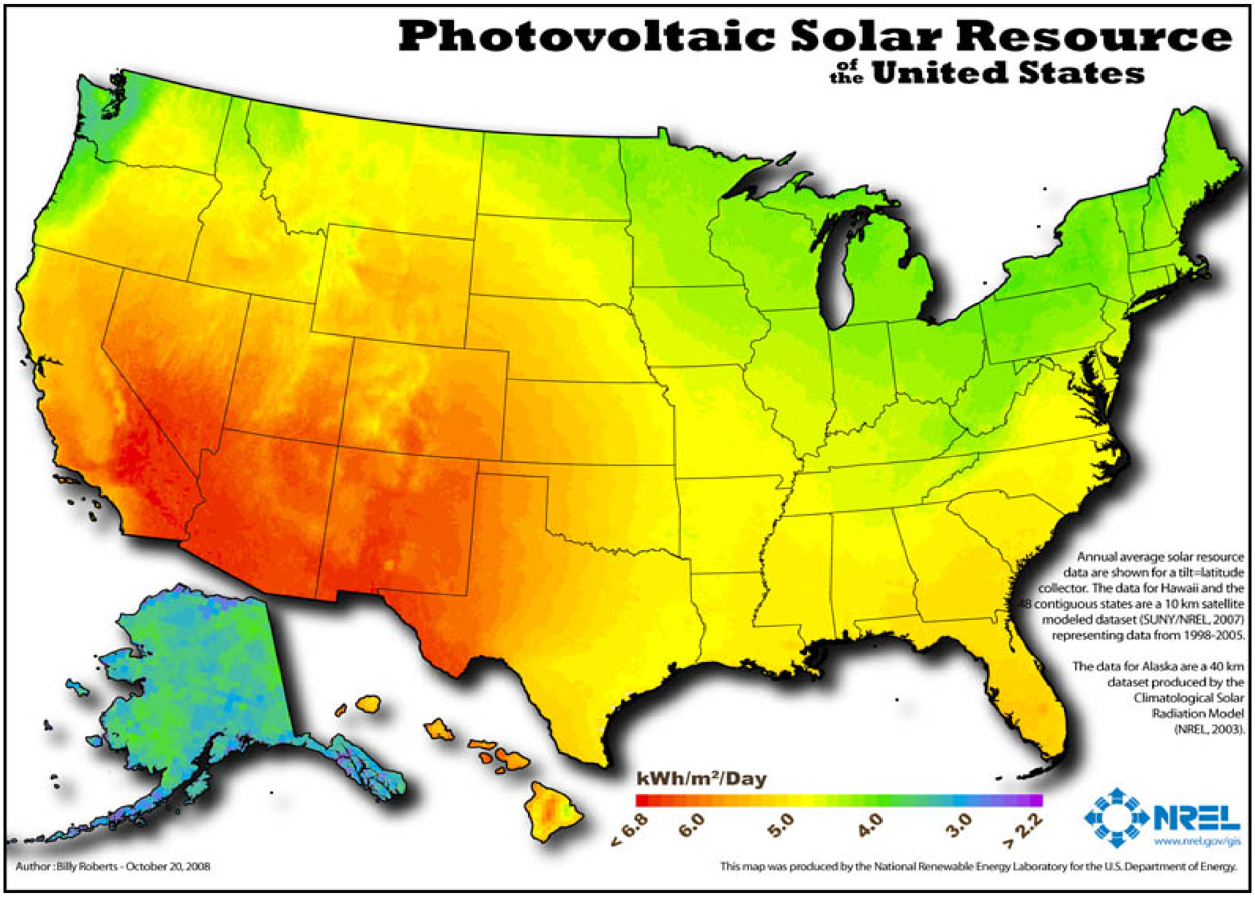


Chart 2: Map of the United States showing the average kWh/m^2/Day produced by solar panels for different regions of the country.

Source: National Renewable Energy Laboratory, 2012.

The Central and South Eastern areas of the United States can effectively use both wind and solar energy, and both would be used in complement to each other. Chart 3 shows the possible regions of the United States that could use wind turbines to produce their electricity. Earlier in my thesis, I spoke about how the capacity factor greatly affects renewable energy. Wind energy in Indiana has a capacity factor of 35-45%, which comes to around \$0.05 per kWh

including externalities, and also has a cheaper price per kWh without externalities than natural gas at \$0.048 (ESRI, 2010).

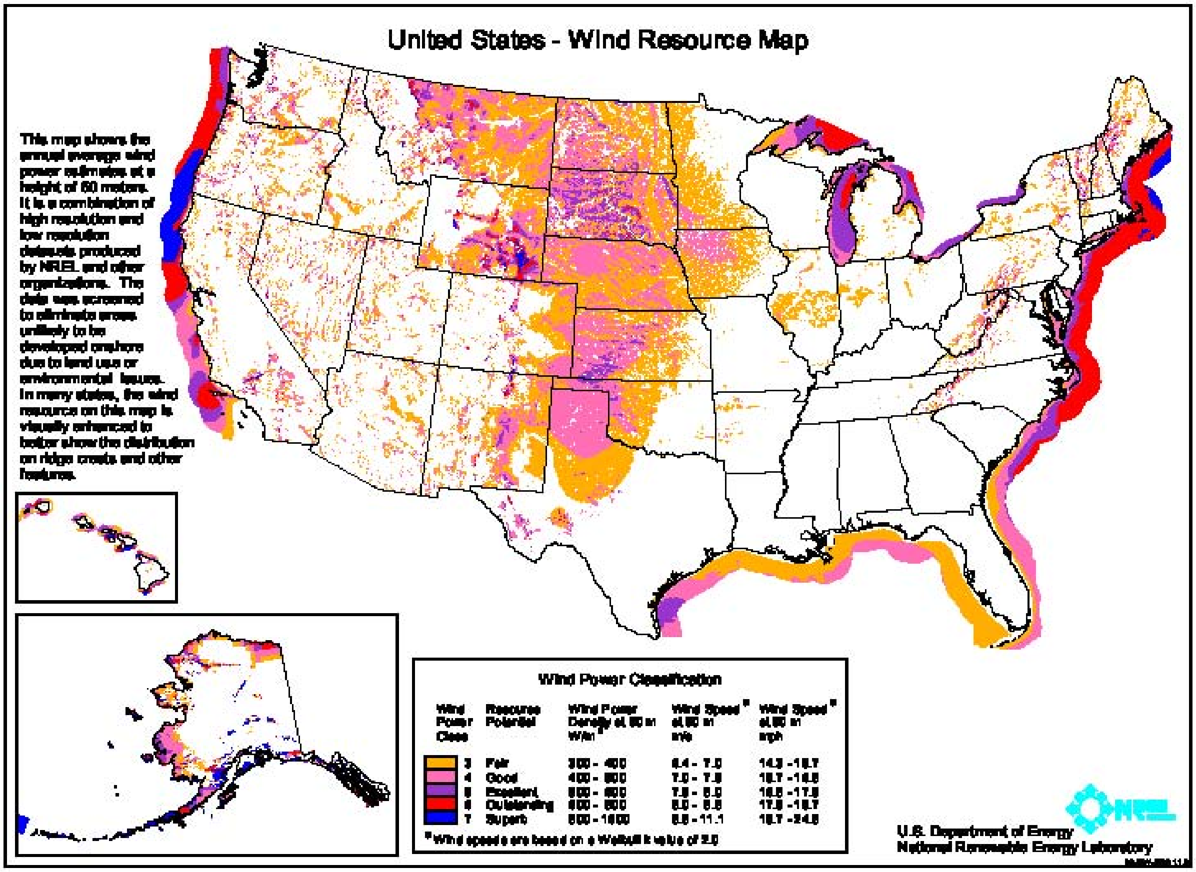


Chart 3: Map of the United States classifying the potential for wind energy ranging from fair to superb based on wind power density and wind speed.

Source: National Renewable Energy Laboratory, 2012.

The North Eastern part of the United States is the only part of the country that could have trouble adapting a 100% renewable energy policy. In this part of the country, solar energy would only be cost effective in the summer months because throughout the rest of the year it receives the lowest amount of solar radiation in the country. Wind energy is readily available along the coastline, but it is unknown if the electricity produced can be effectively distributed throughout

the whole north eastern region. If storage technologies for electricity become more advanced, then it would be possible for the Northeast to have its electricity solely supplied by wind energy. Solar energy can still be used to produce enough electricity to cover a household's energy needs, but it would not be cost-efficient. If the United States were to begin transitioning to renewable energy, the North East should be the last to transition. While wind would have a strong presence in this area in the future, there are new renewable energies such as biomass that are beginning to become more financially viable that could be able to solve the North Eastern renewable energy dilemma if advanced electricity storage technologies fall short of expectations. Since the United States is adopting renewable energy at such a slow pace, it is realistic to assume that one of these newer renewable energies would become cost effective to use by the year 2030, based on the massive advances in the last decade.

Something that could block the way of a renewable energy future in the United States are the public and political responses to failed renewable energy investments by the Energy Department. Out of the approximately forty clean energy projects that received federal funding under the American Recovery and Investment Act of 2009, three have so far filed for bankruptcy. Some of these failed investments could have been avoided if the White House had been more patient, listened to experts, and gotten better research regarding the companies. For example, in the case of Solyndra a few weeks before the loan was to be approved, officials in the Office of Management and Budget were beginning to worry that Chinese companies could threaten Solyndra's sales with cheaper units and asked that the loan announcement be postponed. But those worries were dismissed and the announcement went ahead as planned, and Solyndra received a $535 million loan from the Department of Energy. The company's shut down and bankruptcy in August 2011 stemmed from overestimating how expensive solar power would be.

It’s business plan involved developing copper indium gallium selenide solar cells to compete with those made of silicon which were at historically high prices during 2009 (Perez, 2011). Solyndra’s solar panels had a cylindrical design, which would have been cheaper than those made of silicon because they wouldn't need expensive motors to move them to track the sun or expensive mounting brackets to protect them from the wind. However, Chinese technicians found how to cut the cost of silicon solar cells through R&D funded by the government; the cost of silicon panels dropped by almost half and were much cheaper than those made by Solyndra, even with the motors and mounting brackets, causing Solyndra’s technology to become obsolete.

Beacon Power received a $43 million loan from the Department of Energy to install a flywheel grid storage system. Flywheels absorb and dispatch quick bursts of power onto the grid to maintain a balance between supply and demand, and are a zero emissions energy storage system. The company had never been profitable and filed for bankruptcy in October 2011. Unlike Solyndra, about 70% of the initial investment can be recovered because the asset continues to generate revenue and Beacon Power will continue to operate after being bought out by Rockland Capital, a private equity firm (LaMonica, 2011). Many compare Beacon Power to Solyndra, though the comparison is not a valid one because the two companies had very different business plans. Additionally, the investment in Beacon Power’s technology was still beneficial to the taxpayer because the energy storage system is still useful and fulfills a new purpose, unlike Solyndra’s solar panels.

Ener1 is an electric vehicle battery manufacturer that went bankrupt in January 2012 after receiving a $118 million loan from the Department of Energy in 2009. Much of the loan was used to bail out its top customer Think Global, an electric car company that had filed for bankruptcy on at least three previous occasions. Ener1 had provided loans and other investments

to help out the car company on previous occasions as well, even though the majority of the electric cars produced were sent to Europe, many of which faced three separate recalls. After Ener1 received support from the government, it purchased $18 million stock of Think Global, which gave Ener1 a 31% stake in Think (Chesser, P., 2012). Ener1's dependence on such a weak automaker dragged it to bankruptcy after Think had trouble paying back debts to Ener1 and was unable to buy more batteries. Ener1's technology was used in the U.S. military, and now there is a growing scandal since both Ener1 and Think Global were bought out by Boris Zingarevich, a Russian businessman. He had been Ener1's largest shareholder since 2002 and a major shareholder in Think, and has close ties with Russian President Dmitry Medvedev. The Department of Energy, the Navy, nor the Army had checked for foreign ownership before awarding grants and contracts to use the technology. On April 4th, 2012 the Treasury Department's inspector general found that the department's review for the Solyndra was rushed and that federal financial experts had only about a day to complete their review of the company. Clearly Solyndra was not the only company whose financials and background were skimmed over, and investigations are being undertaken for the rest of the renewable energy companies.

Despite the political complications renewable energy companies are facing in the United States, there are countries that are either already running off 100% renewable energy, or have plans to meet that goal in the nearby future. Germany accounted for over 50% of worldwide 2011 solar panel sales, and is the most significant market for solar panels. Other countries that are important players in the solar panel market are France, Italy, Spain, Australia, and the United States. In a study sponsored by the University of Osnabrück, it was found that about 20% of Germany's rooftops were suitable for solar panel installation, and that at full potential, solar power could meet the entire energy needs of homes around Germany (ESRI, 2010). Generating a

map that shows all suitable rooftops, the project turned over its findings to city officials and has begun to turn into a reality due to positive public response. The maps may be seen online at: http://geodaten.osnabrueck.de/website/Sun_Area/viewer.htm (Osnabrück. 2012). A reason for the surge in the production of renewable energy in Germany was that people who produce it can sell the excess electricity they don't use at fixed prices for 15-20 years. This helped those that wanted to use renewable energy, and didn't want to buy or have the roof space for solar panels, have access to renewable energy, and had the effect of paying back the costs of construction for the owners more quickly. This type of policy should be implemented throughout the United States; currently only 42 state governments require utility companies to purchase surplus renewable energy from individuals. Germany was the top global producer in renewable energy in 2011, producing 20% of its electricity needs through renewable energy: 8% from wind, 5% from biomass, 3% from hydroelectric, and 3% from solar. Almost all of these values are more than twice as high than the United States' with the exception of hydroelectric. Germany has pledged to reduce greenhouse by 40% below 1990 levels by 2020, and by 80-85% by 2050 from 1990 levels. In order to achieve this goal, Germany plans to transform its electricity supply to 100% renewable energy by 2050. It is the first country of significant political importance and population to seriously address the energy crisis and do what needs to be done in order to have a secure future.

After Germany publicized its intentions, other countries (mainly in Europe) began increasing their renewable energy requirements and competing to be the first country to run 100% off renewable energy. Scotland announced on May 20, 2011 that it is targeting to run off of 100% renewable energy by 2020. As of March 2012, it is on track to this goal and in fact beat its renewable energy target of 31% by an extra 4%. Currently, Iceland is the only country that

obtains 100% of its electricity through renewable energy, 87% of which comes from hydropower and 13% from geothermal. Petroleum-fueled power plants are only used as backups in emergencies and situations of abnormally high electricity demand. Iceland contributes 0.01% to the world's carbon emissions, and would be even lower if it's transportation sector stopped using fossil fuels.

In the 1990's, the United States was the global leader in renewable energy. Now, the United States is far behind other countries. For solar energy in 2011, the United States was the 4th highest producer, with Germany, Italy, and Japan taking the lead. Germany produced almost six times as much solar power as the United States. For wind power in 2011, the United States was the 2nd highest producer, with China in the lead producing 33% more than the U.S. For hydroelectric energy in 2009, the United States was in 4th place, with China, Canada, and Brazil in the lead. China produced 2.6 times as much electricity using hydropower than the United States. Although the United States is no longer a leader in renewable energy, our country is a leader in pollution: the U.S. is the second highest per capita carbon emitter and the second highest carbon dioxide emitter in the world. China is the world's worst polluter in terms of carbon dioxide emissions, but it is ranked 44th in terms of per capita emissions, which means that the United States emits a lot more carbon per person (4.4 times more) than China.

Current Distribution of Energy Sources for the Production of Electricity in the U.S.

From the calculations made in Figure 1, I then needed to calculate the current weighted average total cost of electricity for 2011 in order to compare the market prices, externality costs, and total costs of producing electricity for the United States on sources of energy with the lowest externality costs against those sources of energy the Obama Energy Plan will lead us to by 2030.

I calculated the percentages in Figure 3 from individual megawatt values for each energy source, and I allocated “other” renewables (which included wood, black liquor, other wood waste, biogenic municipal solid waste, landfill gas, sludge waste, agriculture byproducts, other biomass, geothermal, solar thermal, non-biogenic municipal solid waste, batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, tire-derived fuel, and miscellaneous technologies) into the wind and solar percentages because they only represented 0.26% of U.S. electricity production, so that only the main sources of energy in the U.S. for which I calculated total costs per kWh would be included.

Using the information in Figure 3, I was able to calculate the weighted average cost of electricity for 2011 in three different ways: total cost, market price, and the cost of externalities. I found these values by multiplying the “% of total” values I calculated in Figure 3 by the corresponding cost values from Figure 1. I then added the values together to find the weighted average of each cost. Calculations can be seen in Figure 4. Using the totals calculated for these three different weighted averages, it will be possible to compare different distributions with different percentages of energy sources and see how this will affect the market price, total cost, and externalities cost. However, before comparing the different weighted averages of producing electricity for the United States on sources of energy with the lowest externality costs against those sources of energy the Obama Energy Plan proposes, it is first necessary to analyze what the energy plan supports and if it is feasible for the future.

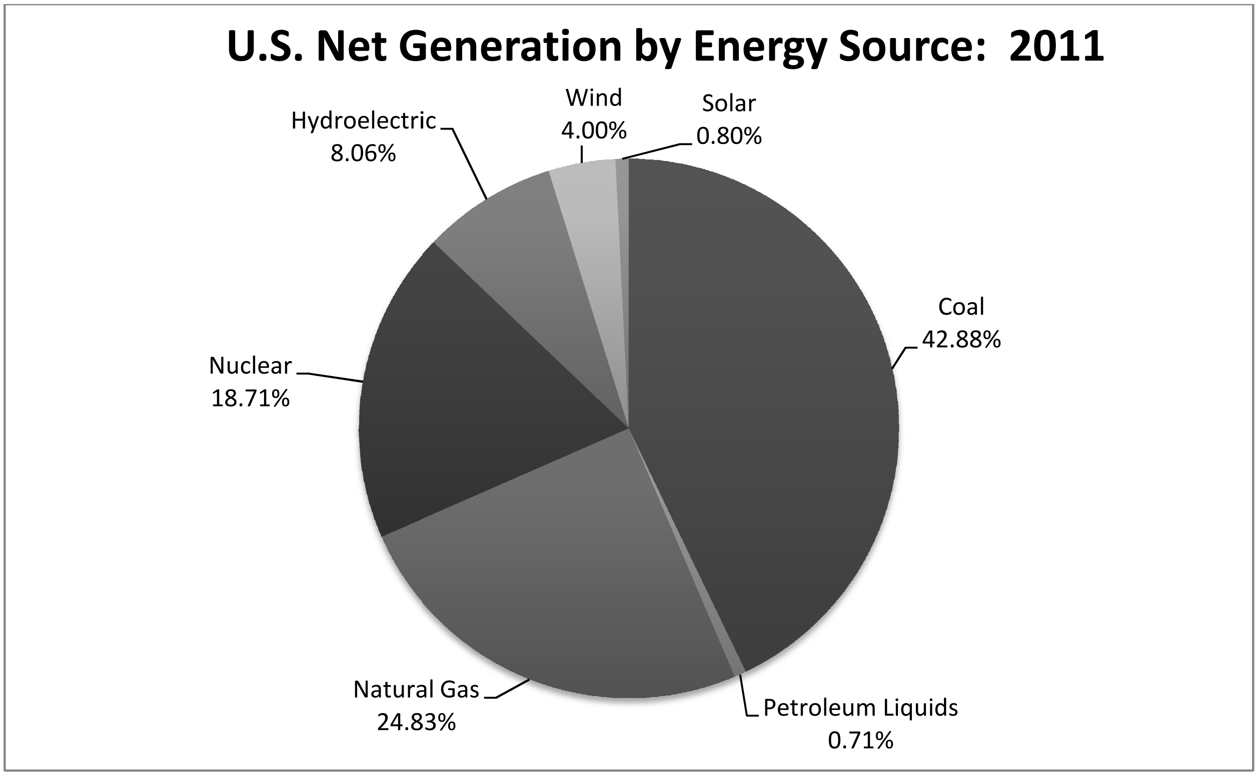


Figure 3: Breakdown of percentages of the types of energy used to generate electricity in the US

U.S. Net Generation by Energy Source	Coal	Petroleum Liquids	Natural Gas	Nuclear	Hydroelectric	Wind	Solar	Total
2011								
Thousand Megawatthours	1,353,490	22,504	783,665	590,560	254546	126,230	25,246	3,155,768
Percentage	42.89%	0.71%	24.83%	18.71%	8.07%	4.00%	0.80%	100.00%

Source for Megawatthours: U.S. Energy Information Administration, 2012.

Explanation of what is included in various energy sources for Figure 3:

Coal: Anthracite, bituminous, subbituminous, lignite, waste coal, and coal synfuel.
Included in Petroleum Liquids: Distillate fuel oil, residual fuel oil, jet fuel, kerosene, and waste oil.
Included in Natural Gas: Blast furnace gas, propane gas, and other manufactured and waste gases derived from fossil fuels.

Figure 4: Calculating cheaper yet cleaner distributions of sources of electricity

2011 US Electricity Generation by Source & Weighted Average Cost per kWh

Energy Source	% of Total	Total Cost per kWh	Market Price per kWh	Externalities Cost per kWh	Weighted Avg Total Cost	Weighted Avg Market Price	Weighted Avg Externalities Cost
Coal	42.9%	$0.10	$0.05	$0.06	0.044	0.020	0.024
Natural Gas	24.8%	$0.06	$0.05	$0.01	0.016	0.013	0.003
Nuclear	18.7%	$0.06	$0.04	$0.02	0.011	0.008	0.003
Hydroelectric	8.1%	$0.03	$0.03	$0.01	0.003	0.002	0.000
Petroleum	0.7%	$0.21	$0.16	$0.05	0.002	0.001	0.000
Wind	4.0%	$0.08	$0.08	$0.00	0.003	0.003	0.000
Solar	0.8%	$0.11	$0.10	$0.01	0.001	0.001	0.000
Totals:	100.0%				$0.080	$0.049	$0.031

Obama's Energy Plan

The energy plan was released on March 30, 2011, and is a blueprint of Obama's actions for improving the supply, market price, and lowering the externality costs of energy sources that are used both to produce electricity and fuel transportation. The most important component of the plan is a commitment to phasing out coal in the United States by strongly increasing our reliance on natural gas. The reasoning for this was because it was found that the United States had an abundance of natural gas which could replace coal, and the huge spike in supply would decrease the market price, making it even cheaper than the current price of coal. Most of this supply was to be found in the Marcellus shale, located in Marcellus New York, and was thought to be able to provide us with a 100 year supply of natural gas. Additionally, it was thought that replacing coal with natural gas could decrease carbon emissions, and that this abundance of a cheap domestic energy source could eliminate our dependence on foreign oil, which Obama reinforced by providing incentives for creating cars that can run on natural gas. However, the feasibility of substituting coal with natural gas for these reasons has become unlikely, given evidence from a recent study by the U.S. Geological Survey which indicates that there is nearly 80% less natural gas in Marcellus shale than previously thought (Urbina, 2011). Marcellus shale would have originally provided a 100 year supply of natural gas, but that estimate is now 20 years. This information was released in August 2011 and estimates for other locations have been decreased as well, but the U.S. government is still on track to having coal become substituted with natural gas. This decrease in theoretical natural gas supply will drastically increase the predicted price of natural gas that aided the Obama administration in choosing a natural gas future. Additionally, our foreign dependence on energy will likely grow after the Marcellus shale becomes depleted. On March 27th, 2012, the Obama administration announced rules limiting

carbon-dioxide emissions from new power plants that will effectively block the construction of most new coal-burning plants, making natural gas even more attractive as a fuel for generating electricity. Another commitment in the energy plan is to expand the production of natural gas worldwide, in order to curb the heavy use of petroleum in developing countries as a source of producing electricity due to a lack of indigenous fuel or infrastructure. It is important to note that though some externality damages can be priced, the actual damages such as the thinning ozone cannot be fixed through human intervention. Only through the reduction of harmful emissions can climate change and the damage to the environment begin to regress. Thus, while it makes sense from a short-term financial perspective (the total kWh including externality cost for gas is lower than wind's and solar's), it may not make sense from an externality and long-term global health perspective.

At a seemingly contradictory point, the report states that the U.S. will work with Mexico and South America to increase oil production and secure additional reliable supplies. By this point in my thesis, the reader should know that petroleum has the highest externality cost (which applies to vehicles as well). This works against the energy plan's commitment to hybrid, clean energy, and electric vehicles. If all of the United States immediately transitioned to electric cars, there would not be significant decrease in carbon emissions, because most of the energy sources producing the electricity isn't clean, and replacing the petroleum (that is typically used to fuel cars) with coal or natural gas in the form of electricity is not enough. It is first necessary to replace the fossil fuels that produce electricity with clean energy before switching to electric-fueled transportation for there to be a justifiable benefit.

The report also talks about continuing to issue permits for 10,000 megawatts of renewable energy projects by the end of 2012. This is necessary because the government has

been slow to respond to the funding of renewable energy prior to the Obama administration. Red tape and regulatory road blocks have slowed approvals for projects for years in some locations. Some states offer incentives and tax credits for renewable energy, but renewable energy is still not as competitive as fossil fuels on market price. To help advance this, $46 billion in tax subsidies for fossil fuel production were eliminated in the 2012 budget. Thus, although the Obama administration is not directly contributing more to renewable energy through subsidies or incentives, clean energy sources are still benefitting from the slow increase in the market price of fossil fuels.

Lastly, the report assures access to the critical minerals needed for components of wind turbines and solar panels. These technologies need materials with unique properties, such as rare earth elements, which are at risk due to location, vulnerability to supply disruptions, and lack of suitable substitutes. China and other countries have already begun stockpiling these raw materials, and it is necessary for the U.S. to have access to them as well. Obama's budget includes "research and development in all aspects of critical minerals, including environmentally safe and responsible extraction, mineral recycling and reuse." The budget also supports efforts to tap the enormous offshore wind resources along America's coastlines and the Great lakes (White House, 2012).

Comparing Obama's Plan to a Renewable Future

Figure 5a shows an estimate of what the Obama energy plan will lead the United States energy distribution to be in the year 2030, which I discuss in depth later in my paper. In the report, it was stated that wind should become 15-20% of U.S. energy production by the year 2020, and that coal would slowly be replaced with natural gas. Specific plans for hydroelectric

power were not stated in the report; instead, they were simply included in the president's commitment to increasing renewable energy. The current 8.1% of U.S. 2011 electricity generation coming from hydroelectric has been reported to only be a third of the available hydroelectric potential in the United States, so I multiplied 8.1% by 3.3 and rounded to 26.6% (University of Oregon, 2012). Since the amount of megawatts produced when the study found the hypothetical limit is very close to the current 2012 value, I did not have to change the 3.3 multiplier to account for the difference. The limit for hydroelectric electricity usage in the U.S. is due to geography and free flowing water availability constraints. For Figure 5a, I used a value of 15% for hydroelectric, which is double the current value, but still low enough that it wouldn't require a moderate investment in hydroelectric R&D (which rises as it approaches the hypothetical 26.6% limit).

The energy plan does not specify a goal for solar energy, and though it talks about investing more in R&D and a few new projects, it seems that wind and natural gas will be the new substitutes for coal, thus I only increased the percentage for solar energy slightly to account for California's renewable portfolio standards and similar programs. Finally, I chose a zero percent value for petroleum, because currently it is only used as an emergency source of electricity production. Under the Obama energy plan, coal would fulfill that role and it was even stated that coal would still be used for a good amount of time.

Figure 5b shows a 100% renewable energy future, and I assigned the percentages myself. These energy sources were based on choosing the lowest externality costs possible, regardless of market price and total cost. Thus, I eliminated coal, natural gas, and petroleum completely. I chose not to include nuclear energy into this distribution, because I felt that the energy of the future should not have Damocles risks associated with it, and that after I updated the externality

cost for nuclear following the Fukushima incident, I felt that the added costs of choosing a different source of energy were justified. However, I would recommend that the country transition by eliminating petroleum, coal, and natural gas, and replacing those with wind and solar before eliminating nuclear energy, based on their market costs. Figure 5b has a 26.6% value for hydroelectric, which is the hypothetical limit to hydroelectric electricity in the United States. Wind power is capable of generating nine times the current total US electricity consumption, or about 37,000,000 gigawatt-hours annually, so there was no need to limit the percentage (Wind Power Monthly, 2012).

The renewable energy distribution has a decrease of 86% in the weighted average cost of externalities from the 2011 distribution, which would make a very noticeable change in CO_2 emissions and would be the ideal start to creating a carbon neutral or carbon negative nation. The downside is that the weighted average market price increases up by 50%, but it is important to note that the weighted average total cost is approximately 3% lower than the 2011 distribution. This means that the United States could essentially shift most of its current externality costs into the market price per kWh of electricity, and have a much healthier impact on the environment for approximately the same total cost. This also means that if externality costs and damages had to be paid, or were included in the prices of electricity, then it would be more logical to switch to renewable energy than to pollute and pay approximately the same price. By dividing -86.22% by 50.62%, I found that for every dollar spent on market price, $1.70's worth of externalities would be eliminated.

The Obama Energy Plan distribution has a 56.29% decrease in the weighted average externality cost from the 2011 distribution, and has a 7.41% increase in the weighted average market price. By dividing –86.22% by 50.62%, I found that for every dollar spent on market

price, \$7.60’s worth of externalities would be eliminated. However, the Obama Energy Plan distribution has 317% the amount of externality costs of the renewable energy distribution, even though it only has a 43% lower market price than the renewable energy distribution. Thus, Obama’s energy plan is not nearly as efficient as the renewable energy plan in bringing down externality costs, though it would lower the total market price paid. Both plans would decrease total costs and externality costs, while increasing the market price from the current 2011 distribution. Thus it really comes down to preference: pay significantly less in market price but do more harm than is necessary to the environment, or pay only a bit less in market price and do the least harm currently possible for producing electricity. What is very clear from this study is that relying heavily on coal is neither cheaper nor cleaner, giving no incentive to continue using it as a source of producing electricity in the United States.

Figure 5a: Estimated Distribution in Year 2030 with Obama's Energy Plan

Energy Source	% of Total	Weighted Avg Total Cost	Weighted Avg Market Price	Weighted Avg Externality Cost
Coal	7.5%	0.008	0.004	0.004
Natural Gas	40.0%	0.025	0.021	0.005
Nuclear	18.7%	0.011	0.008	0.003
Hydroelectric	15.0%	0.005	0.004	0.001
Petroleum	0.0%	-	-	-
Wind	16.0%	0.013	0.013	0.000
Solar	2.8%	0.003	0.003	0.000
	100.0%	$0.066	$0.052	$0.014
% Change in Cost from 2011 distribution:		-17.50%	7.41%	-56.29%

Figure 5b: 100% Renewable Energy

Energy Source	% of Total	Weighted Avg Total Cost	Weighted Avg Market Price	Weighted Avg Externality Cost
Coal	0.0%	-	-	-
Natural Gas	0.0%	-	-	-
Nuclear	0.0%	-	-	-
Hydroelectric	26.6%	0.009	0.007	0.002
Petroleum	0.0%	-	-	-
Wind	42.0%	0.035	0.035	0.001
Solar	31.4%	0.033	0.031	0.002
	100.0%	$0.077	$0.073	$0.004
% Change in Cost from 2011 distribution:		-2.89%	50.62%	-86.22%

Areas for further study

Even if the world were to become carbon neutral today, it would take the planet over a thousand years to recover on its own from climate change without human intervention. Although there are carbon absorption technologies, they are very expensive and do not receive much funding. Current externality costs measure the damage that has been done to the planet, but they do not take into account the future damages that are going to happen or length of time necessary to clean up the environment. They do not take into account the money that will be required to clean the CO_2 out of the air or whatever method scientists will come up with to prevent further climate change. They do not take into account the millions of people who will have to move because the places they live will become flooded with water from rising sea levels, or the many other damages that have already begun to occur.

In my calculations, externality costs remained static. However, externality cost values change depending on the technology used, the percentage distribution and amount of energy sources used, and more. My calculations used recent externality costs and current market prices to evaluate two different distribution plans. This would mean that my calculations are really for a scenario in which the United States were to switch to these distributions right away, although I used percentages and weighted averages so that my calculations could reflect the future distribution as much as was currently possible without having to take into account increasing energy needs, inflation, and other factors. Although market prices could be predicted for the future, research forecasting externality costs is currently not available. Considering that many countries are beginning to or are planning to change energy sources in the near future, it would be difficult to predict what energy sources will be used around the world in 50 years, what environmental consequences they might create, and how they will contribute to overall CO_2

emissions and climate change externality costs. All relevant externality cost research was conducted within the last decade, so it is impossible to find historical externality prices to try and assume an accurate trend. However, it can be inferred that externality costs have risen historically, given that CO_2 levels have been accelerating “super-exponentially” (Gillett, Arora, Zickfeld, Marshall, and Merryfield, 2010). I hypothesize that total costs for fossil fuels (coal, petroleum, and natural gas) have been and will continue rising due to increasing future externality costs. Additionally, I predict that the total costs for solar and wind will continue decreasing over time, due to their low externality costs and rapidly decreasing market prices as renewable technology becomes more advanced. The relationship I am hypothesizing can be seen in Figure 6. The black line to the right of the equilibrium would be the point in time where solar and wind’s total costs are lower than those of coal, natural gas, and petroleum. It is possible that we have already reached this point in time depending on where you place wind turbines and the technology used for converting natural gas into electricity.

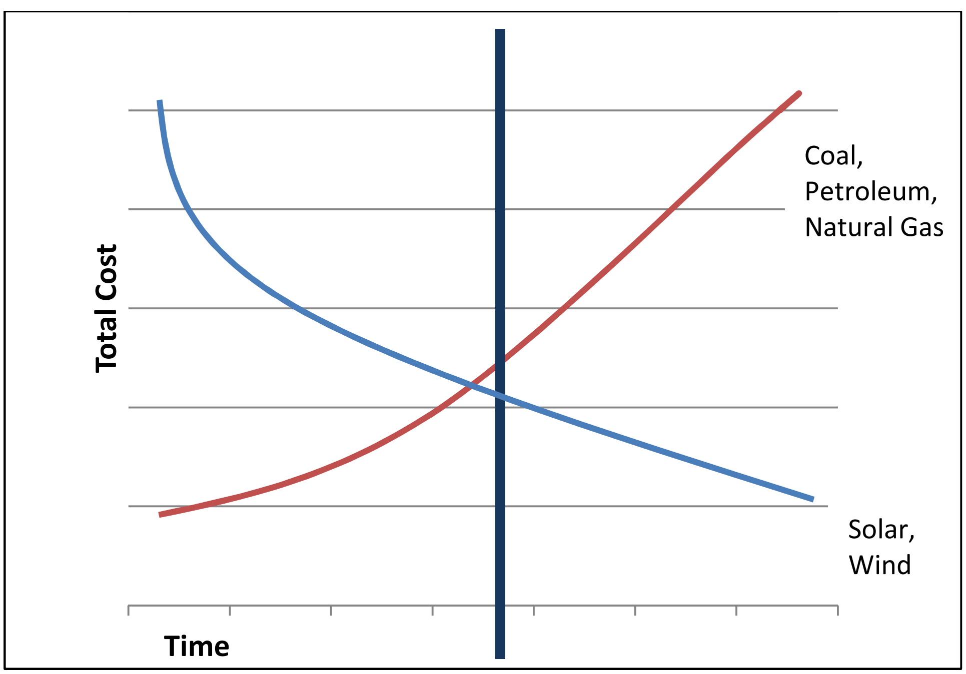


Figure 6: Hypothesized relationship between total costs of energy sources as time goes on.

However, simply comparing the average total costs for each energy source in Figure 2 shows that natural gas still has lower total costs than either wind or solar. I also hypothesize that if we were to follow to Obama Energy Plan, then some of the externality costs would shift from coal and petroleum to natural gas, causing its total cost to rise. This would be because natural gas would become much more widely used, and thus more of the damage to the environment would be attributed to it. This would occur for all energy sources, although I think that solar and wind would have much lower net externality costs. If it could be supported that we are to the right of the equilibrium, then this would strongly support the argument for converting to renewable energy. However, there is currently a lack of research and quantitative analysis for me to support this theory.

Conclusion:

The extent of externalities is strongly linked to the technology and energy source used. Pollution can be reduced for current energy sources through installation of end-of-pipe technology or the substitution of the energy source used. However, given that my calculations were for recently built power plants with end-of-pipe technology already in place in accordance to environmental law and regulations, changing the technology of an inherently damaging substance will not decrease externality costs by a high enough value to justify the continued use of it. Instead, the United States should begin to strongly transition towards the use of cleaner energy sources so that economies of scale will bring down the costs of constructing the renewable energy technology, which makes up most of the cost per kWh. If the United States followed the Obama Energy Plan, and the decrease in externality damages by switching from coal to natural gas end up not curbing climate change, then there is the possibility that we would

have to switch to wind and solar energy anyway, wasting time and money by not switching over immediately. Having to switch energy sources yet again may even bring more opposition to change and prevent the change from occurring as rapidly as needed. Of course, this is assuming the best case scenario, ignoring the possibility that the external damages from natural gas could potentially be even more detrimental than coal when used to produce electricity on a massive scale (Sheppard, K., 2011).

To continue facilitating the change to cleaner energy, the United States should continue to support and heighten requirements on emission limits, subsidies for renewable and cleaner energy sources, and a decrease in subsidies for coal and oil to increase their prices and discourage power plants from using them. These measures would enable the United States to convert to a cleaner source of energy, which would then give us the possibility of transitioning to a clean, electric-based means of transportation. The longer we continue to pollute through our choice of energy sources, the longer and more expensive it will be to clean up. It is time that the United States re-took its place as the leader in renewable energy and set the example for the rest of the world to follow to create a healthier and more responsible future.

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