What is the Impact of CO_2 Emissions in the Countries that Use the PUREX Process?

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Abstract

This paper examines the assumption that as the usage of nuclear power as a percent of total electricity production in countries that use the PUREX process increases CO_2 emissions (metric tons per capita) will decrease. The data gathered was analyzed from 1960 until 2010, a period chosen to encompass the evolution of the nuclear power industry in the United States. Analyses of variance were conducted to measure the changes in variables over time. Studies were also performed between the different variables to determine if there was a significant relationship at the 0.05 level. Results found a very low positive correlation between the amount of nuclear power used and CO_2 emissions.

Keywords: PUREX, nuclear power, CO_2 emissions

Introduction

After World War II, the United States government had the desire to develop nuclear energy for peaceful civilian purposes. Since the beginning of electricity production from nuclear power plants, legislators have had a fiduciary duty to make the decisions that will protect the public and the environment. To do so, the ecological effects of the nuclear fuel cycle must be monitored, especially radiation and carbon dioxide emissions, hereafter referred to as CO_2. Legislators must determine the safest methods for storing nuclear waste, also known as spent nuclear fuel, for the environment and the public. The United States has created fifty-eight thousand tons of spent nuclear fuel over the last fifty years; this waste is located in storage facilities and pools across the country and poses a serious risk to the environment (Widder, 2009). Instead of storage, one option of a type of nuclear reprocessing is Plutonium Uranium Extraction, also known as the PUREX process, already in use by China, France, India, Japan, the United Kingdom, and Russia (Simpson & Law, 2010). The purpose of this study is to determine if the countries that use the PUREX process utilize more nuclear power than the United States, and if so, is there less CO_2 being emitted into the atmosphere.

Need for this Study

Throughout the history of nuclear power in the United States, one of the goals has been to produce a cleaner form of energy for commercial use, with the first power plant producing energy for commercial purposes in Shippingport, Pennsylvania in 1957 (Bupp & Derian, 1978). The nuclear power industry grew quickly in the 1960s but started to slow in the 1970s and 1980s due to safety concerns caused by the first significant nuclear power plant accident at Three Mile Island (Bupp & Derian, 1978; Char & Csik, 1987). The Three Mile Island accident was the result of human error, equipment failure, and design flaws leading to the reactor core overheating due to the coolant system failing (Ragheb, 2007). This accident did cause a small amount of radioactive material to be released into the atmosphere but ultimately caused no serious harm (Ragheb, 2007; Hatch et al., 1989; Talbott et al., 2000). The topic of storing spent nuclear fuel and waste disposal has been a point of political contention since the 1980s when Congress realized the need to move the radioactive waste away from nuclear power plants. A much more recent controversy arose over one such project, the new repository at Yucca Mountain in Nevada that has never been operational (Nuclear Energy Institute, 2012).

Locally this is a concern in South Carolina because the storing of nuclear waste is a problem that the state faces with having the largest amount of toxic waste in the country, besides Washington State (Rosen, 2012). There are state agencies that monitor the nuclear waste situation, for example, South Carolinas Budget and Control Board's Energy Office has a Radioactive Waste Disposal Program that monitors the disposal site in Barnwell, South Carolina (BCB, 2012). The storing and transporting of spent nuclear fuel can affect the local economy and environment. One negative impact has been seen in studies of the real estate markets in South Carolina. The transportation of spent nuclear fuel has negatively affected property values in highly populated urban areas, which is of concern to state legislators (Jenkins-Smith, 1999). The high-level radioactive waste is also of environmental concern because it is being stored at reactor sites that were not originally designed to hold the large amounts of waste for a long period of time (Ahearne, 2000). Legislators' concern for the states wellbeing is playing out in the courtroom, with South Carolina Attorney General, Alan Wilson, suing the U.S. Department of Energy because the agency impeded the law that was passed by Congress by discontinuing the building of Yucca Mountain (Rosen, 2012). The reason state legislators are focused on the decision to close Yucca Mountain is because this location would have been the primary resting place for the nuclear waste that is currently being created and stored in South Carolina.

The need for another option for what the United States does with the spent nuclear fuel that is produced came to the forefront in the legislature when a tsunami hit Fukushima, Japan in 2011. The tsunami created a nuclear power plant crisis that was rated a six out of seven on the International Nuclear and Radiological Event Scale (*The Telegraph*, 2011). The International Atomic Energy Agency defines level six as a serious accident with the release of radioactive material that requires planned countermeasures (IAEA, n.d.). The tsunami was discussed at length at the special hearing before a Subcommittee of the Committee on Appropriations, United States Senate on March 30, 2011. During this hearing, experts The Honorable Gregory B. Jaczko, chairman of the Nuclear Regulatory Commission, and Dr. Peter B. Lyons, acting Assistant Secretary for Nuclear Energy for the Department of Energy, explained how the loss of water in the spent fuel pools in Japan would cause the fuel rods being stored there to overheat and meltdown, causing the rods to ignite and force the radioactive waste to cover a highly populated area (ABC World News, 2011; Makhijani 2011). Since Japan currently uses the PUREX process, they have less nuclear waste stored in the spent fuel pools than the United States because the waste is being reprocessed for use in the power plants (Makhijani 2011). If a similar event happened in the United States, there would be an even greater threat of radiation exposure (Makhijani 2011). If the United States were to transition into reprocessing spent nuclear fuel by using the PUREX process, the volume of high-level nuclear waste stored across the country would be reduced by twenty percent (World Nuclear Association, 2011).

Research Questions

The research question in this study is: "what is the impact of CO_2 emissions (metric tons per capita) in the countries that currently use the PUREX process?" By studying the independent variables of electricity production as a percent of total and kilowatts per hour, hereafter referred to as kWh, from coal, hydroelectric, natural gases, oil, renewable, and nuclear sources, the investigator will assess changes in the dependent variable of CO_2 emissions (metric tons per capita). This research hypothesizes that as the total electricity production from nuclear power increases, the CO_2 emissions will decrease. In this study, CO_2 emissions produced by the countries that use the PUREX process will be analyzed and compared to the United States, which does not use reprocessing. Data extracted from the World Data Bank will be analyzed from 1960 until 2010, a period chosen to encompass the evolution of the nuclear power industry in the United States.

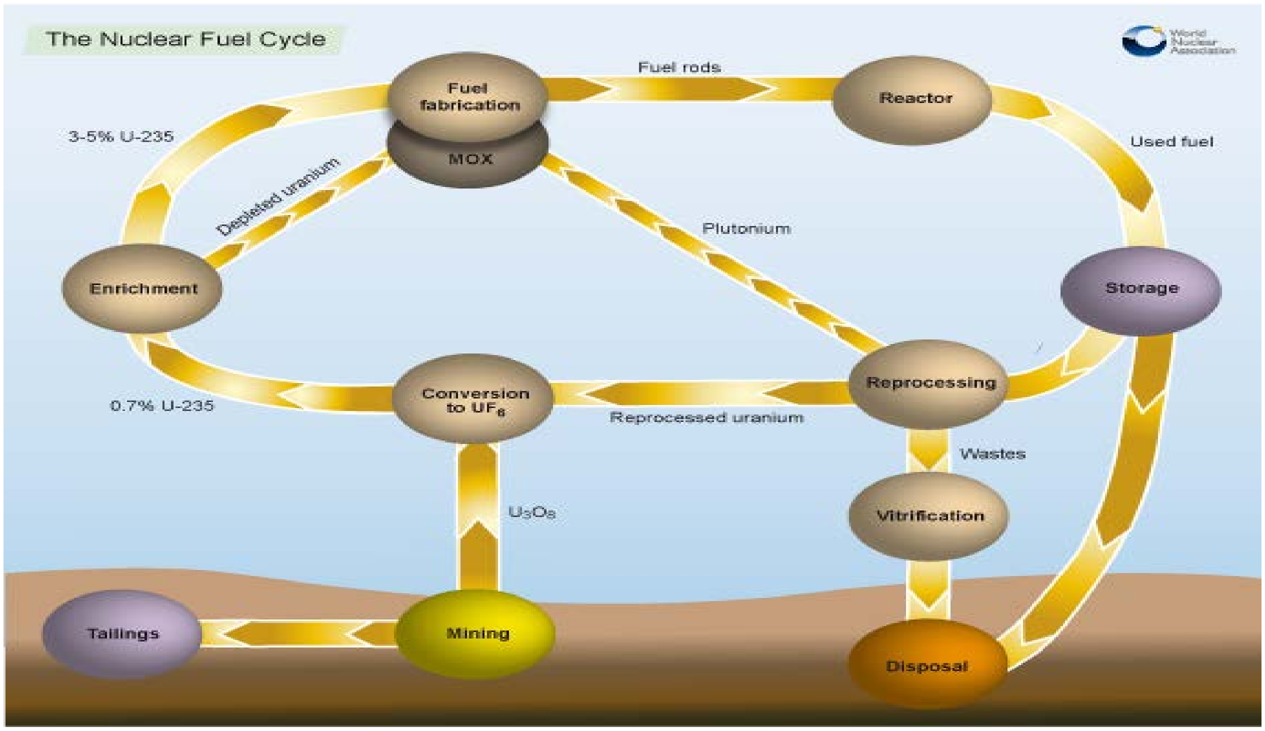
Anticipated Outcomes

Scientists, researchers, and government agencies have been evaluating the environmental impact of the nuclear fuel cycle since the inception of nuclear power in the United States. The PUREX process is a type of reprocessing the United States could use to lessen the amount of radioactive waste being stored across the country. Through this analysis, the PUREX process will be evaluated, and the information gathered will help legislators determine if they should support implementation of this process. In pushing for the United States to go to the PUREX process, legislators hope the nation will become more dependent on nuclear power and in turn will help to preserve the environment for future generations. The next section will review some of the scientific studies conducted on the effects of the nuclear fuel cycle on the environment and how they relate to this research.

Literature Review

The Science of the Nuclear Fuel Cycle

Figure 1: Nuclear Fuel Cycle



To understand the PUREX process, one should understand the basics of the nuclear fuel cycle, which is comprised of the front and back end. See Figure 1 (World Nuclear Association, 2011). The front end of the nuclear fuel cycle consists of mining and milling, conversion, enrichment, and fuel fabrication (Wilson, 1996). In the beginning of the process, uranium is mined, crushed, and then extracted by a chemical process (Lenzen, 2008). Dry uranium ore, known as "yellowcake," is the product of this process (Lenzen, 2008). The uranium goes through the process of conversion because it must be in the gas form, uranium hexafluoride, known as UF_6, before it can be enriched (Lenzen, 2008).

Since most power reactors require enriched uranium fuel, the nuclear plants will use the centrifuge process with thousands of spinning vertical tubes; research is currently being done on a laser enrichment process, which looks to be promising (World Nuclear Association, 2011; Moses et al., 2009). At the fuel fabrication plant, enriched uranium is converted into powder and then formed into pellets, which are then placed in rods made of zirconium alloy (Lenzen, 2008). These rods will form fuel assemblies, which will be used in the nuclear reactor core (World Nuclear Association, 2011).

The back end of the cycle consists of storage, reprocessing, and recycling before disposal of the nuclear waste (World Nuclear Association, 2011). Since the used fuel assemblies that are taken from the reactor core are extremely radioactive and give off a great deal of heat, they are stored in ponds located at the reactor site (Fthenakis & Kim, 2007). These storage ponds are used as a barrier against radiation exposure and to disperse heat from the spent fuel (World Nuclear Association, 2011). Another option of storage is dry storage; here the used fuel assemblies are placed in special engineered facilities and cooled down by air (World Nuclear Association, 2011). The longer the assemblies are stored in the short-term, the easier it is to handle due to decay of radioactivity before it is either reprocessing or stored (World Nuclear Association, 2011). The final step in the back end of the fuel cycle, without reprocessing any waste, is storage (Fthenakis & Kim, 2007).

Why Nuclear Power?

One reason nuclear power has become a widely used form of electricity production is because it is a more clean form of energy compared to fossil fuels and coal as can be seen through lower CO_2 emissions throughout their life cycles. Another advantage to using nuclear power is the cost-effectiveness of the process. Some experts would say that with the construction of new power plants comes increased employment therefore positively affecting the economy while others believe the costs to maintain the plants as well as the transportation and storing of nuclear waste is too high. Studies have found nuclear power plants are more cost efficient compared to fossil fuel power plants in the operating and fuel costs (Mandel, 1976). Even though the costs to generate power are less expensive, the initial investments in nuclear power plants are significantly higher (Mandel, 1976). There are several concerns when using nuclear power for electricity purposes one being the issue of spent nuclear fuel that must be dealt with once the fuel cycle is complete.

Radiation Effects on the Public

In determining whether the United States should reprocess spent nuclear fuel, legislators must consider the radiation effects on the environment of the nuclear fuel cycle and the storing of nuclear waste. Each year in the United States 2,100 to 2,400 tons of spent nuclear fuel is created by nuclear reactors (Widder, 2009). The radiation effects of the nuclear fuel cycle can affect not only the environment but also nuclear power plant employees. Radiological protection standards are measured by the Sievert, Sv (World Nuclear Association, 2011). This unit of measurement takes into account biological effects of different types of radiation (World Nuclear Association, 2011). The Millisievert, mSv, one-thousandth of a Sievert, is how the dosage to humans is measured (World Nuclear Association, 2011). The International Commission on Radiological Protection has created a standard dose limit for employees of nuclear power plants of 20 mSv per year not to exceed 50 mSv per year (Yim & Ocken, 2001; Hendee, 1992).

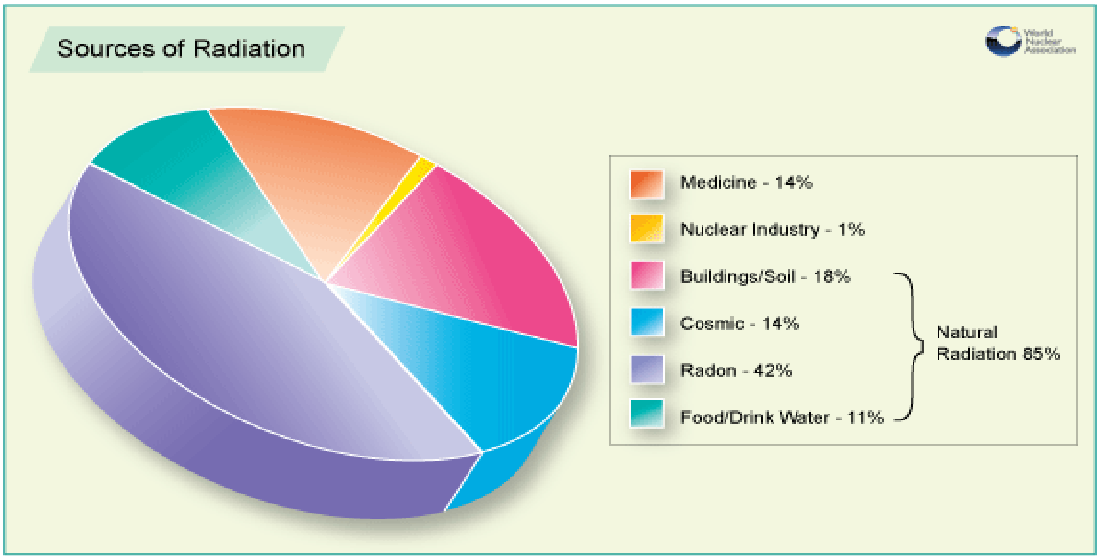
Another concern of radiation exposure from stored waste is medical issues that may arise, such as birth defects and cancer (U.S. NRC, 2011). Studies in the United Kingdom have found an increase in cancer in children living near nuclear power plants (Jablon et al., 1991). In response to the United Kingdom study, another study was done in the United States through a survey that was given to populations that live close to nuclear power plants (Jablon et al., 1991).

This study found there was an increased cancer risk in the counties that had a nuclear power plant (Jablon et al., 1991). Other studies have been done to show the effects of radioactive material on pregnant nuclear power plant employees, who must be extremely diligent when protecting their fetus especially during the eight to fifteen weeks following conception (Hendee, 1992). Several studies have been done to determine if congenital defects, such as Down Syndrome, occur as a result of parents working at nuclear plants or with radioactive materials, however it was found that there is no association between the two (Green et al, 1997; Doyle et al., 2000; Sever et al., 1986). Other studies have found that radiation can cause stillbirths. A study on the workers of the Sellafield Nuclear Reprocessing Plant in the United Kingdom found a strong correlation between the father's total exposure to radiation before conception and the chance of their baby being a stillborn (Parker et al., 1999).

Radiation & Government Agencies

There are a plethora of different sources of radiation, natural and manmade (Thorne, 2003). The EPA states nuclear power plants make up less than one-hundredth of a percent of an Americans total radiation exposure (EPA, 2007). The Nuclear Regulatory Commission has found through their research, the amount of radiation emitted from a nuclear power plant is so small that citizens living near a nuclear power plant will be exposed to less than one percent of radiation in a one-year period (U.S. NRC, 2012). In addition, the World Nuclear Association found fifteen percent of radiation worldwide is manmade, with one percent coming from the nuclear industry (World Nuclear Association, 2011). See Figure 4 (World Nuclear Association, 2011). In controlling the risk of radiation from nuclear materials, Congress instructed several regulatory agencies to develop radiation standards all with the same purpose, to reduce radiation exposure.

Figure 4: Source of Radiation



One regulatory agency in particular has been working for decades on protecting the American people when it comes to radiation exposure, the Environmental Protection Agency. The EPA has created standards that are in place to protect the public and individuals working within the vicinity of radiation, such as medicine, nuclear power, mining, and waste management (EPA, 2007). The Environmental Protection Agency must be diligent in monitoring the negative radioactive effects on the environment that can come from storing nuclear waste, be it in a repository or cooling pools. The radiation from stored nuclear waste can affect the environment by leaking radiation into the groundwater, which can affect humans through consumption of well drinking water and marine food (Weber et al., 1984; Krishnamoorthy et al., 1997). In addition to contaminating groundwater, radioactive material can be inhaled through excavation during construction and prolonged exposure at the site of the stored waste (Krishnamoorthy et al., 1997).

The Nuclear Regulatory Commission and Department of Energy regulate radiation standards, nuclear power reactors, and any use of nuclear material (EPA, 2007). These government agencies ensure all nuclear power plants have emergency plans in place to protect the public from a possible radiation exposure in the event radioactive materials were to be released into the environment, similar to the event in Japan caused by the tsunami. In the event there is an emergency, state and local governments are primarily responsible for protecting the public and environment followed by federal agencies such as Department of Homeland Security, Food and Drug Administration, Energy, Agriculture, and Health and Human Services (EPA, 2007; Hendee, 1992).

Studies have found reprocessing nuclear waste actually reduces the level of radiation in high-level waste as well as being less harmful to the environment (Widder, 2009; Litjenzin et al., 1980; Ghisellini et al., n.d.). Not only does reprocessing, such as the PUREX process, reduce radiation levels it can also lower the heat load on the repository by removing elements that cause heat, such as plutonium, neptunium, and minor actinides (Widder, 2009; Forserg, n.d.). Thus, the timeframe for long-term storage can be significantly decreased from hundreds of thousands of years to a few thousand (Widder, 2009; Forserg, n.d.; Litjenzin et al., 1980).

CO_2 Emissions & the Nuclear Fuel Cycle

CO_2 is defined as a colorless, odorless, and non-poisonous gas created by the combustion of carbon formed during respiration (Random House Dictionary, 2012). Emissions are defined as the release of greenhouse gases into the atmosphere over a specific area during a period of time (OECD, 2005). Over the past decade, global warming and greenhouse gas emissions, especially CO_2, have sparked a heated debate between the right and left in both the political and public arena; with one side saying, these emissions have no effect on global warming while the other side is in complete disagreement (Holtz-Eakin & Selden, 1992).

The United States produces large amounts of CO_2 emissions through everyday life but citizens and legislators should be aware of how much is actually being produced and how the emissions can be lessened by using more clean sources of energy such as nuclear power (Soytas et al., 2006). Between 1990 and 2000, greenhouse gas emissions in the United States rose to seventeen percent (Soytas et al., 2006). In addition, during this same timeframe twenty-four percent of the total carbon dioxide emissions for the world were produced by the United States (Soytas et al., 2006). Electricity production continues to increase in the United States and in 2007, forty two quadrillion British thermal units, BTUs, of electrical energy was produced generating six billion metric tons of CO_2 emissions (Widder, 2009). One example of a source of the increased emissions comes from coal power plants, a plant that will produce 1000 megawatts of electricity will release close to six million tons of CO_2 into the atmosphere per year (Ghisellini et al., n.d). Studies have projected the worlds electricity demand to increase by seventy-five percent by 2020, the United States electricity demand to increase by twenty-six percent by 2030, and with only a five percent increase in nuclear construction (Widder, 2009; Lester 2003). This increase calls for the need for more forms of renewable energy and the demand for nuclear power is expected to rise (Widder, 2009).

CO_2 Emissions & Global Warming

There is a need for lower CO_2 emitting electricity production because of the effects that global warming has on every living being on the planted (Ghisellini et al., n.d.). The global temperature has increased 0.6 degrees Centigrade, 33.08 degrees Fahrenheit, over the past one hundred years and is expected to rise rapidly (Root et al., 2003). Plants and animals have been able to adapt to this steady change by evolving but with the rapid increase that is expected ecosystems and the wild species that inhabit them should be a point of concern to legislators

(Root et al., 2003; Parmesan & Yohe, 2003). To illustrate the point, a study was conducted with information gathered from one hundred and forty three other studies; the analysis found eighty percent of animals and plants did adjust with the temperature change (Root et al., 2003). In addition, the study found global warming as a leading contributor of destroying habitats, which will cause a change among all species leading to possible genetic changes and eventual extinction (Root et al., 2003; Parmesan & Yohe, 2003).

In addition to affecting animals and plants, global warming also has the ability to have harmful effects on human health (Ghisellini et al., n.d.). Studies have shown global warming to cause floods and droughts, which can harm crops making them susceptible to infection and infestation, which can lead to malnutrition and death (Epstein, 2000; Rosenzweig & Hillel, 1998). Flood and droughts also have the ability to create waterborne diseases (Epstein, 2000). During a time of flood, sewage and other contaminants can effect drinking water and during a time of drought, contaminates that would otherwise remain weakened become concentrated and contaminate drinking water (Epstein, 2000). In addition, human health in the United States can be affected by global warming through the mosquito (Epstein, 2000; Reeves et al., 1994). During times of greater heat, the mosquito population grows and causes the insect to bite more which could spread diseases such as West Nile virus and Malaria (Epstein, 2000).

In the fight against global warming legislators are looking to more clean sources of energy for the United States to utilize. According to the International Nuclear Energy Agency forty years of nuclear power has decreased CO_2 emissions per year by 1.2 billion tons and in the event the world did not utilize nuclear power CO_2 emissions would increase by 2.5 billion tons per year (Ghisellini et al., n.d; Adamantiades & Kessides 2009). Although nuclear power is considered a more clean energy source, with some calling it carbon free, there is still the creation of greenhouse gases at different stages of the life cycle (Fthenakis & Kim, 2007; Beerten et al. 2009). Even before the process of creating nuclear power through the nuclear fuel cycle, CO_2 emissions are emitted indirectly through the construction of the nuclear power plant as well as any facility that provides energy, one example being through the mixing of cement that is actually being used to build the plant (Fritsche, 2006; Sovacool, 2008). In addition, emissions at extremely low levels are emitted through the process of mining and processing, enrichment of uranium, fuel fabrication, and through the daily operations of the nuclear power plant (Fritsche, 2006; Weisser, 2006; Sovacool, 2008). Many studies have been done on the amount of CO_2 emissions that the nuclear fuel cycle actually produces but none can come to a consensus on the actual amount produced because they focus on different aspects of the cycle (Ghisellini et al., n.d.). For example, some studies focus on the quality of the uranium being used, while another focuses on the method that was used for mining and extraction, and another focuses on older forms of technology when fabricating fuel (Ghisellini et al., n.d.). A small amount of CO_2 is emitted during the last stages of the nuclear fuel cycle during long-term disposal (Lenzen, 2008). This study found that overall waste management is responsible for a range of five to thirteen percent of greenhouse gas emissions (Lenzen, 2008).

Although studies have found there are CO_2 emissions in the nuclear fuel cycle, the emission levels are significantly lower than that of fossil fuels and coal, making it possible in the future to replace these forms of electricity while satisfying global demand (Ghisellini et al., n.d.). Rodney Ewing, Professor of Nuclear Engineering and Radiological Science from the University of Michigan, did a study of the nuclear fuel cycle and the environmental impacts and found the nuclear fuel cycle creates 0.5 gigatonnes of carbon a year with fossil fuels creating almost sixteen times more, at 8 gigatonnes (Ewing, 2008). In the event a nuclear power plant created the same amount of electricity as coal fire plant there would be 1.8 gigatonnes less of CO_2 emitted per year (Lester, 2003).

The Future of Nuclear Energy & Public Perception

The future of nuclear energy with the renewed interest in nuclear power production must be considered in order for there to be a significant future impact on CO_2 emissions (Whitfield et al., 2009). For there to be an interest in future nuclear growth in the United States, citizens must understand the risks (Whitfield et al., 2009). Massachusetts Institute of Technology, MIT, conducted a survey of 1,350 American adults where two-thirds of the respondents did not believe that nuclear waste could be stored safely for a long period of time (Lester, 2003). Although many Americans feel that waste could not be stored safely, many independent expert assessments show that mined repositories, such as Yucca Mountain, are able to safely contain nuclear waste (Lester, 2003). In this same survey MIT found, most Americans would rather nuclear power usage be reduced and strongly supported the expansion of renewable energy. Finally in this survey, people were divided into two groups, either concerned about global warming or not, and the survey found no correlation between the concern over global warming and the support for nuclear power (Lester, 2003). Several studies have come to the same conclusion that gender, age, education, income, or political association has no effect on an individual's interest in nuclear power generation, even if CO_2 emissions were reduced, but there is a strong desire among policy makers for a renewal in nuclear power (Whitfield et al., 2009).

This study focuses on the ecological impact of CO_2 emissions but it is important to make mention of the negative impacts on economic growth since it is the voters that ultimately pay the price through taxation (Stern, 2006). Studies have shown the negative economic effects and costs of CO_2 emissions can be devastating to every person on the planet and if ignored it will eventually undermine economic growth (Stern, 2006). One study found no correlation between the rate at which an economy develops and the yearly flow of CO_2 emissions while another study found that CO_2 emissions did increase as the per capita income rose; further study is needed on this topic for legislators to make a sound decision (Holtz-Eakin & Selden, 1992; Sengupta 1996).

Why the PUREX Process?

The PUREX process is a type of reprocessing that separates plutonium and uranium through several cycles of chemical extraction (Simpson & Law, 2010). There is close to ninety-five percent of original uranium, four percent of waste, and one percent of plutonium in used nuclear fuel when it is reprocessed (Bunn et al., 2003). In the beginning of the PUREX process, the used fuel rods are broken up and leached in a nitric acid solution because there is hardware that is still attached to the broken up pieces of fuel rods that must be extracted (Simpson & Law, 2010). The uranium that is recovered will be sent back for conversion and then will be re-enriched (European Nuclear Society, n.d.). After the PUREX process takes place, plutonium is combined with enriched uranium to create mixed oxide, known as MOX fuel (Caracappa, 1997). MOX fuel can be an alternative to the low-enriched uranium fuel used in light water reactors and can also provide a means of burning weapons-grade plutonium from military sources to produce electricity (World Nuclear Association, 2011; Caracappa, 1997). When MOX fuel is reprocessed, it can only be used again at a maximum of three times before disposal (Caracappa, 1997). See Figure 2 (European Nuclear Society, n.d.) and 3 (World Nuclear Association).

Figure 2: PUREX Process

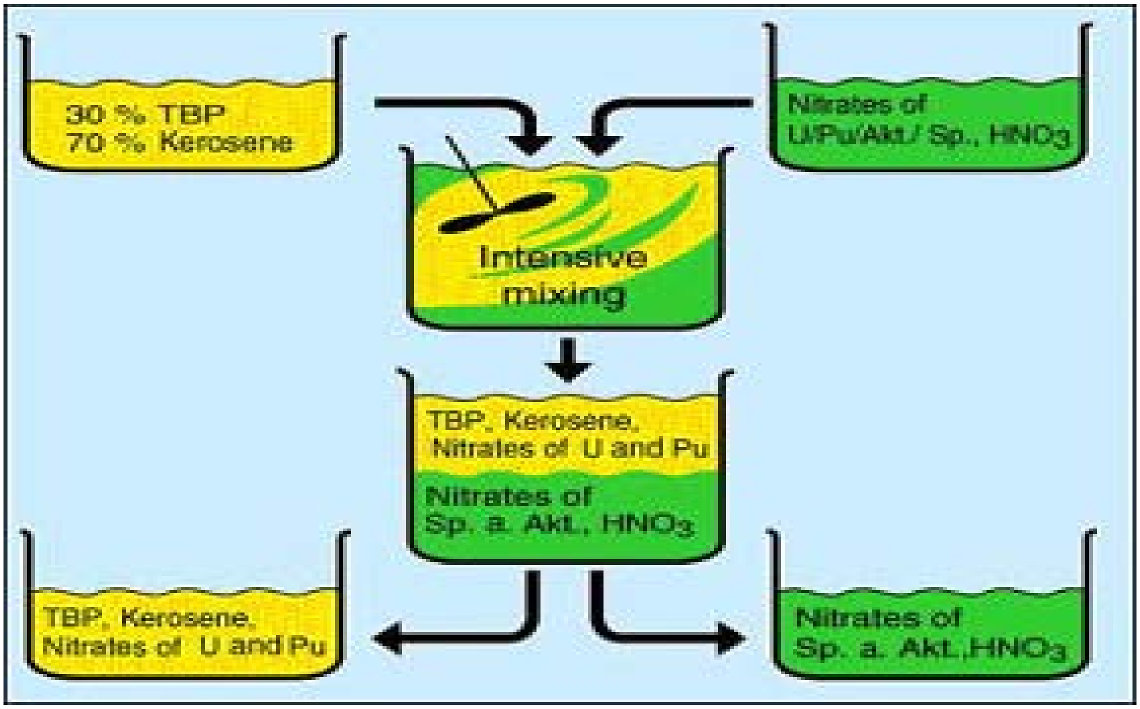
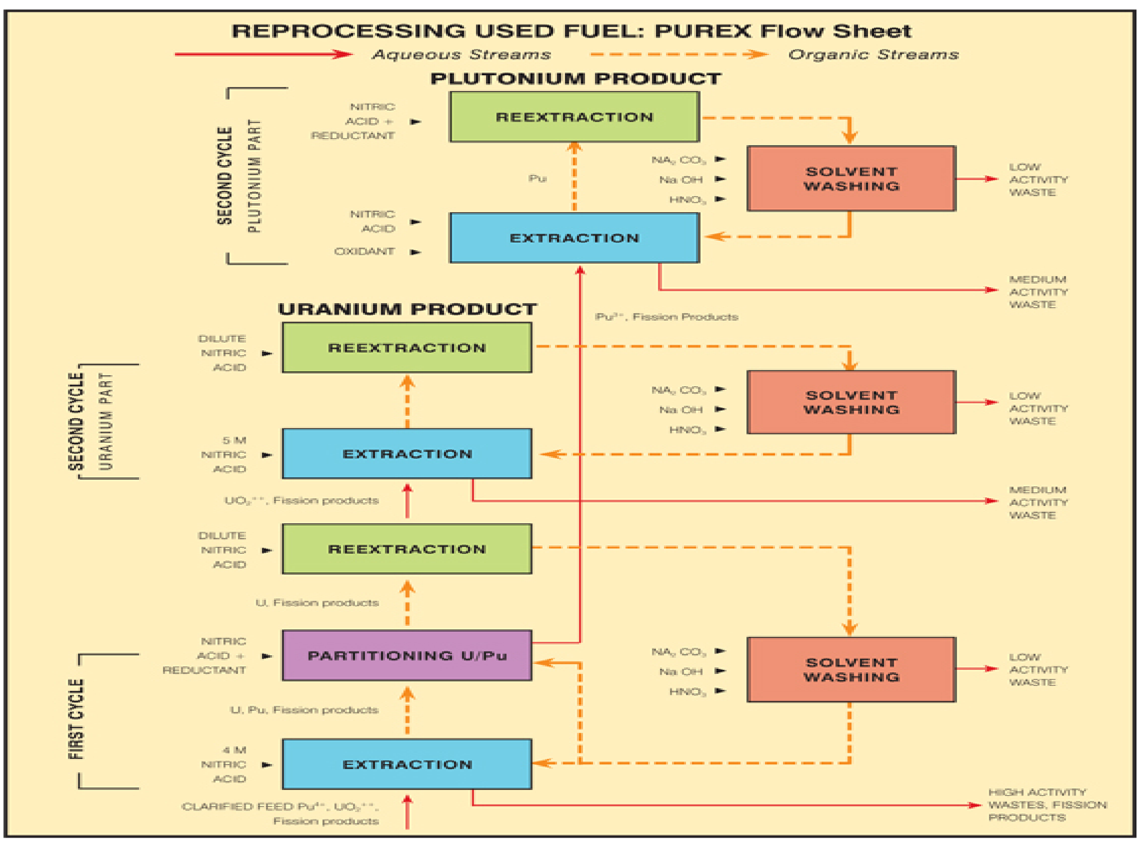


Figure 3: PUREX Flow Sheet



After the nuclear waste has been reprocessed, it goes through the process of vitrification (Bunn et al., 2003). Vitrification is the conversion of dry powder waste into glass (Random House Dictionary, 2012; World Nuclear Association, 2011). Nuclear power plants use vitrification because it is an acceptable form to solidify waste (Sheng et al., 2000). The glass that is produced is poured into stainless steel canisters, each holding 400 kg, 880 pounds (World Nuclear Association, 2011, Fthenakis & Kim, 2007). The canisters make it possible for transportation and storage while providing protection from radiation (World Nuclear Association, 2011). The final step in the back end of the fuel cycle is the disposal of the nuclear waste (Fthenakis & Kim, 2007).

China, France, Japan, India, Russia, the United Kingdom are the countries that currently reprocess their spent nuclear fuel through the PUREX process. Studies project China and Japan to expand their efforts of reprocessing of nuclear waste with China opening a large scale reprocessing plant that will be operational in 2025 and with the opening of Japan’s new large scale plant currently in the testing phase (Hogselius, 2009). France and the United Kingdom were the leading pioneers of reprocessing nuclear waste but it has been predicted that France will continue to slowly lose reprocessing customers and the UK will move to direct disposal starting with the close of the Magnox reprocessing plant in 2012 (Hogselius, 2009).

There are numerous reasons why a country would want to reprocess nuclear waste, the most obvious being to reduce the amount of spent nuclear fuel in storage, which takes up nine times the volume of vitrified high-level waste, the product of reprocessing (Hogselius, 2009). One reason to use reprocessing would be for military ambitions and non-proliferation because reprocessing nuclear waste is the only way to create plutonium for the use in weapons of mass destruction (Hogselius, 2009). Another reason why countries choose to reprocess spent nuclear fuel is because they have the desire to be the first in the world to master the complete nuclear fuel cycle (Hogselius, 2009). In addition, the political culture of a country has great influence in determining if a country reprocesses nuclear waste or not. Studies have found the more authoritarian countries such as China and Russia have implemented this process with greater ease then counties with governments similar to the United States. Lastly, geological conditions play a significant role in determining if countries choose reprocessing. For example, direct disposal of waste is not a viable option in a country such as Japan due to an unstable geology and dense population (Hogselius, 2009).

In the United States, building repositories such as Yucca Mountain is a point of political contention among many; legislators must consider the possibility of implementing a reprocessing system such as the PUREX process. One study done by Schneider, Deinert, and Cady found there are advantages to creating reprocessing plants in the United States. They found that the most cost effective way to change the United States from storage to reprocessing is to create a system of government run plants without working with any private entities and they also suggest a “nuclear power production fee” is the best way for the government to recoup the costs of establishing these plants (Schneider et al., 2009). This situation would be especially beneficial in South Carolina to the local environment and economy by helping to lower the amount of nuclear waste that is stored across the state.

The literature reviewed in this study can help to explain the research question by understanding the effects of the nuclear fuel cycle, the storing and reprocessing of spent nuclear fuel, and CO_2 emissions. Most studies done on the topic of the impact of the nuclear fuel cycle do not cover CO_2 emissions regarding countries that use a type of nuclear reprocessing. Although there is a great deal of research done on the topic of the nuclear fuel cycle, the issue of environmental impacts needs to be studied in regards to the countries that use any form of reprocessing spent nuclear fuel. Since there are not many studies that focus environmental issues of reprocessing nuclear waste, this study could help to fill the gap, which could assist legislators in their push for nuclear energy reform. This study will analyze nuclear power consumption in countries that reprocess nuclear waste and the impact on CO_2 emissions. If the hypotheses are supported, and CO_2 emissions decrease because nuclear power usage increases, this could provide legislators with the information needed to support the transition from storing to reprocessing nuclear waste.

Data and Methods

The purpose of this study is to determine if the countries that use the PUREX process utilize more nuclear power than the United States, and if so, is there less CO_2 being emitted into the atmosphere. The hypotheses are based on the theory that nuclear power does not directly emit CO_2 emissions; however a very small amount is emitted throughout the nuclear life cycle (Fritsche, 2006; Fthenakis & Kim, n.d.; Sovacool, 2008; Weisser, 2006; Dones et al., 2004). Based on the other forms of energy production analyzed in this study, except for renewable and hydroelectric, nuclear power has significantly lower CO_2 levels (Sovacool, 2008). See Table 1 (Sovacool, 2008). The main hypothesis is as the percentage of total electricity production from nuclear power increases, the CO_2 emissions (metric tons per capita) will decrease. The supporting hypotheses are:

1. The countries that utilize the PUREX process use more nuclear power for electricity.
2. As the total electricity production in kWh, increases, electricity production from nuclear power in kWh will increase causing a decrease in CO_2 emissions.

Table 1: Lifecycle Estimates for Electricity Generators

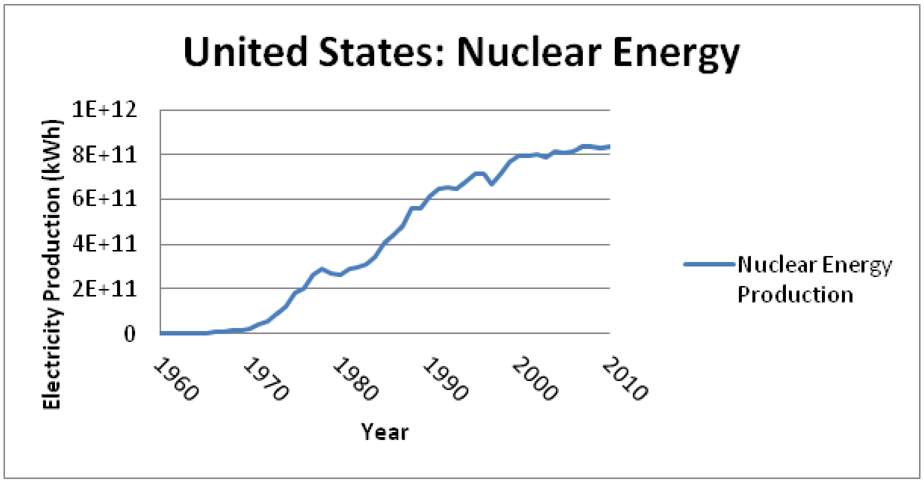
Fuel Source	Capacity/Configuration/Fuel	Estimate (gCO_2e/kWh)
Wind	2.5 MW, offshore	9
Hydroelectric	3.1 MW, reservoir	10
Wind	1.5 MW, onshore	10
Biogas	Anaerobic digestion	11
Hydroelectric	300kW, run-off-river	13
Solar thermal	80 MW, parabolic trough	13
Biomass	Forest wood co-combustion with hard coal	14
Biomass	Forest wood stream turbine	22
Biomass	Short rotation forestry co-combustion with hard coal	23
Biomass	Forest wood reciprocating engine	27
Biomass	Waste wood stream turbine	31
Solar PV	Polycrystalline silicone	32
Biomass	Short rotation forestry steam turbine	35
Geothermal	80 MW, hot dry rock	38
Biomass	Short rotation forestry reciprocating engine	41
Nuclear	Various reactor types	66
Natural Gas	Various combined cycle turbines	443
Fuel cell	Hydrogen from gas reforming	664
Diesel	various generator and turbine types	778
Heavy Oil	Various generator and turbine types	778
Coal	Various generator types with scrubbing	960
Coal	Various generator types without scrubbing	1050

The outcome of this study, if evidence is found to support the hypotheses, could provide a base of knowledge that could assist legislative aides to further their research into the potential environmental impacts of nuclear reprocessing. This information could also have a significant impact on energy reform policy. A correlation showing a decrease in CO_2 emissions and an increase in the amount of nuclear power used in the United States might influence legislators to pursue a type of nuclear reprocessing such as the PUREX process. In addition to the possible environmental impact, studies have been done to show reprocessing would also be the more economical choice, especially in regards to the cost of uranium and the costs of the alternative of long term storage (Bunn et al., 2003).

This study analyzes the data by performing an analysis of variance test, which is used to test equalities of means across different groups (De Veaux et al., 2009). In this study, the countries that use the PUREX process were compared to the United States to determine if there was a similarity in CO_2 emissions and the different forms of electricity production used. CO_2 emissions were analyzed based on the different forms of electricity production to determine if the type of energy production as a percentage of the total directly influences the amount of CO_2 being emitted. In addition, total electricity production kWh was analyzed to determine if as electricity production increases, nuclear power production increases thereby causing a change in CO_2 emissions.

The data for this study was extracted from the World Data Bank, which is a data catalog with access to the world's most comprehensive collection of data on developing economies. The World Data Bank was chosen as the data sources for this research because it provided the most recent data for the dependent and independent variables. The extracted data was compiled and organized in Excel and analyzed using JMP statistical software. The dependent variable in this study is CO_2 emissions measured by metric tons per capita; this was chosen to show the environmental impact per person since the countries being analyzed have varying populations. The independent variables in this study are electricity production as a percent of total production and kWh from coal, hydroelectric, natural gas, nuclear, oil, and renewable. This study uses data from the years of 1960 until 2010. The year 1960 was chosen as the starting year, to show the beginning of nuclear power usage in the United States, with the creation of the first nuclear power plant creating electricity for the public in 1957 (Hohenemser et al., 1977). The launch of nuclear power can be seen in the first ten years; then starting in 1970, nuclear power generation increased and grew over the next thirty years and finally to the plateau of nuclear energy use in the last ten years. (Figure 5).

Figure 5: United States Nuclear Energy



Findings

The ANOVA compared the countries that use the PUREX process and the United States against the CO_2 emissions they produce indicated the United States had the largest mean at 19.25 CO_2 emissions (metric tons per capita), and producing larger amounts of CO_2 than the other countries. (Figure 6). Each country is significantly different from the other, except for Japan and France. No significant difference exists between these two ($P< .05$). (Table 2; levels not connected by the same letter are significantly different at the 0.05 level).

Figure 6: Total CO_2 Emissions by Country

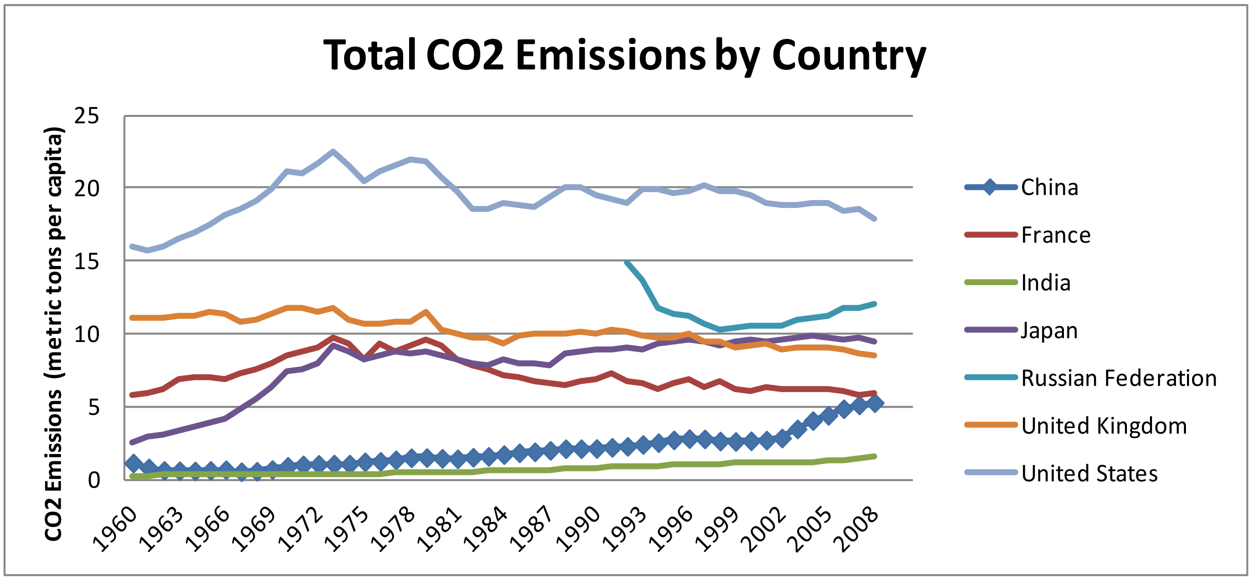


Table 2: ANOVA Results CO_2 Emissions

Level		Mean
United States	A	19.35
Russian Federation	B	11.49
United Kingdom	C	10.25
Japan	D	7.87
France	D	7.24
China	E	2.01
India	F	0.71

It was also of interest to evaluate differences in fuel sources among the countries. An ANOVA was run to determine differences between the types of electricity production between the countries. The results indicate for electricity production percentage of total from coal, China had the largest percentage, the United Kingdom, France, United States, and India with similar means, while Japan and Russia had the lowest. (Appendix A, Figure A1 & Table A1). France had the largest mean for hydroelectricity at 27.28 percent and the United Kingdom used the lowest amount of hydroelectricity with a mean of 1.51 percent. (Appendix A, Figure A2 & Table A2). Russia is the largest consumer of natural gas for electricity purposes with a mean of

44.65 percent and China was the smallest consumer with a mean of 0.33 percent. (Appendix A, Figure A3 & Table A3). Electricity production from oil was greatest in Japan with a mean of 30.01 percent and lowest in India with a mean of 4.87 percent. (Appendix A, Figure A5 & Table A5). In addition, the United States and the United Kingdom utilize electricity production from renewable sources the most with a mean of 1.10 and 1.07 percent and Russia the least with a mean of 0.02 percent. (Appendix A, Figure A6 & Table A6).

Electricity production from nuclear energy has not been around as long as other forms, such as oil and coal because of this all countries in this study utilize a lower percent of nuclear power compared to other energy sources. (Appendix C: Electricity Production by Country). This study found India, Japan, the United Kingdom, Russia, and the United States all utilized a similar rate of nuclear power when producing electricity. India had the largest mean at 18.05 percent; this is due to the spike in nuclear electricity production, from 1978 until 1991, caused by the creation and growth of India's nuclear weapons program (Ganguly, 1999). (Figure 7). Japan, the United Kingdom, and Russia all have similar means in the range from 14-16 percent; this could be due to these countries utilizing more nuclear power because of the PUREX process. Although France and China use the PUREX process to reprocess spent nuclear fuel, they had the lowest means of 3.45 and 0.68 percent. This could be because most of China's and France's electricity production comes from coal and hydroelectric, which is inexpensive compared to nuclear. (Table 3).

Figure 7: Electricity Production from Nuclear by Country

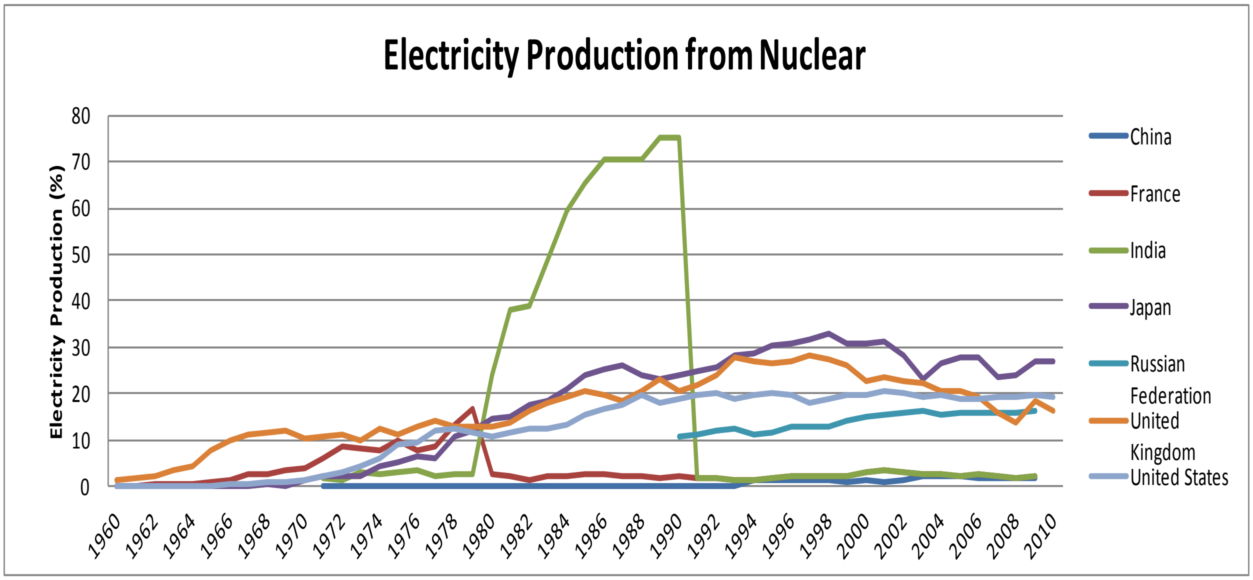


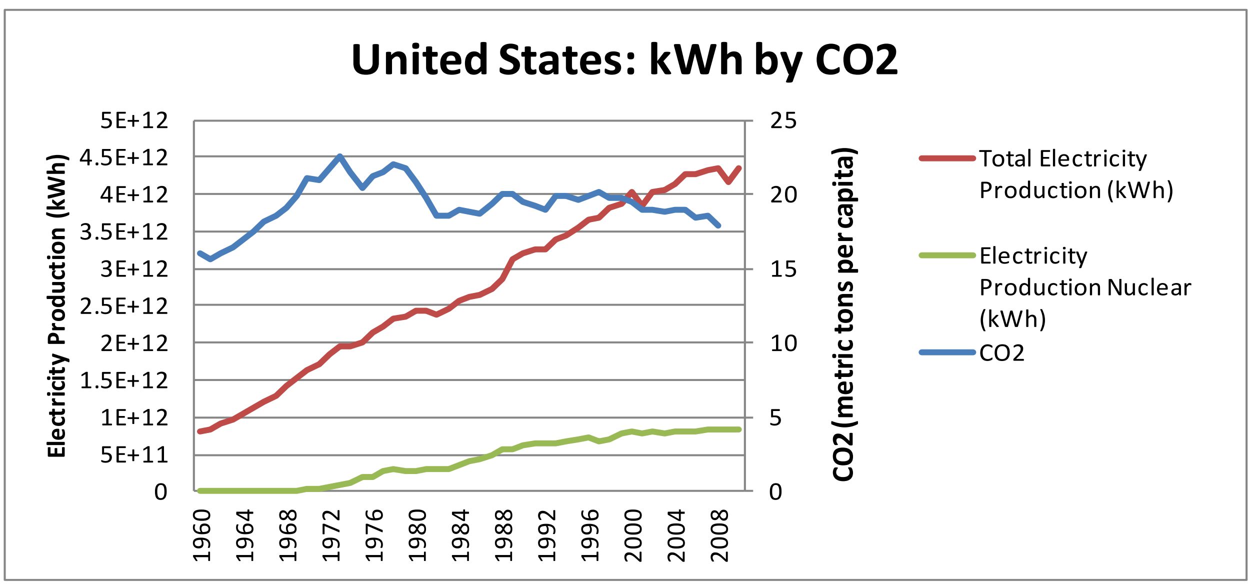
Table 3: Electricity Production from Nuclear % of Total

Level		Mean
India	A	18.05
Japan	A	16.62
United Kingdom	A	16.51
Russian Federation	A	14.00
United States	A	12.47
France	B	3.45
China	B	0.68

The study did not find a strong correlation between the different forms of electricity production and CO_2 emissions. The dependent variable, CO_2 emissions (metric tons per capita), had a mean of 8.68 and a standard deviation of 5.99. Electricity production from coal sources (% of total) had a mean of 47.42 and a standard deviation of 21.71. Electricity production from hydroelectric sources (% of total) had a mean of 16.40 and a standard deviation of 11.56. Electricity production from oil sources (% of total) had a mean of 12.52 and a standard deviation of 13.64. There was a low negative correlation between coal, hydroelectric, and oil with CO_2 emissions, meaning the relationship is very weak. Electricity production from natural gas sources (% of total) had a mean of 11.12 and a standard deviation of 12.81. Electricity production from renewable sources (% of total) had a mean of 0.57 and a standard deviation of 0.83. A positive correlation was found between CO_2 emissions and natural gas as well as renewable, but with such a low value, the relationship is very weak.

When determining if using more nuclear power will decrease CO_2 emissions, this study found a very low positive correlation of 0.11. Electricity production from nuclear sources as a percentage of total electricity production had a mean of 11.54 and a standard deviation of 13.49. This study also found over time as total electricity production in kWh increased for the United States and as the use of nuclear power started to rise, CO_2 emissions (metric tons per capita) did decrease. (Figure 8). In the countries that use the PUREX process, this study found similar results in France, Japan, the United Kingdom, and Russia. India and China did not show a change in emissions as nuclear power production was introduced and as total electricity production increased. (Appendix B for Countries: kWh by CO_2).

Figure 8: United States: kWh by CO_2



Results did not support the main hypothesis that as total electricity production from nuclear power increases, the CO_2 emissions (metric tons per capita) will decrease. A low positive correlation suggests there is a weak relationship between the two. Therefore, this study did find as nuclear power production as a percent of total electricity production increases, CO_2 emissions do not increase drastically. The hypothesis of countries that utilize the PUREX process use more nuclear power compared to the United States, which does not reprocess, was supported in regards to the United Kingdom and Japan. The hypothesis of as the total electricity production in kWh increases, electricity production from nuclear power in kWh will increase causing a decrease in CO_2 emissions was proven in all of the countries except China and India.

Limitations

The few limitations to this study did not affect the results; one limitation being there are not many studies done on a similar topic of analyzing CO_2 emissions of the countries that reprocess nuclear waste. Several studies focus on emissions throughout the life cycles of the different forms of electricity production but the investigator was not able to find any that compare the different countries that use reprocessing to the United States. Another limitation during this study is in regards to the data set provided by the World Data Bank. The data provided from the World Data Bank did not have the dependent variable of CO_2 emissions (metric tons per capita), the independent variables of electricity production percent of total and kWh for coal, hydroelectric, natural gas, nuclear, oil, and renewable for the years of 1960-1989 for Russia. The reason the Russian Federation data was not available could be because of the Cold War, with the War coming to an end with the collapse of the Soviet Union in 1991 (Zubok et al., 1997). In addition, the independent variables were not available for the years of 1960-1968 for India and the years of 1960-1970 for China. The possible reason China did not have data could have been due to the Cultural Revolution which occurred during 1966-1976. The revolution in China had a direct impact on India during the 1960s with border disputes eventually causing the Sino-Indian War (Smoker, 1969). In addition, the data provided for CO_2 emissions (metric tons per capita) for China seemed low, which raises the question of accuracy of the reporting of the emission numbers.

Analysis & Conclusion

The findings from this study do provide a different component to the research that has previously been done on the topic of environmental impacts of nuclear power. This study is different in its analysis of the energy mix of the countries that reprocess their spent nuclear fuel and in determining if there is a relationship between emissions and electricity production. As previously stated in the literature review, studies on the topic of electricity production and CO_2 emissions analyze the life cycle of the different sources and the finding in this study of a weak relationship between CO_2 emissions and electricity production from nuclear power support this (Fritsche, 2006; Fthenakis & Kim, n.d.; Sovacool, 2008; Weisser, 2006; Dones et al., 2004).

Using the data from the World Data Bank, this paper theorizes that there is a link between the amount of CO_2 emissions being released into the atmosphere and electricity production from nuclear power. The results of this paper do not support the hypothesis, as nuclear power usage as a percent of total electricity production increases CO_2 emissions will decrease. This study did find a steady decline in emissions in the United States as nuclear power usage was introduced and continued to grow over the years. (Figure 8). Of all of the countries in this study, the United States did emit the greatest amount of CO_2 emissions (metric tons per capita), which may be due to less nuclear power being utilized as compared to some of the other countries in this study. Based on the results of this study, it is the belief of the investigator that utilizing more nuclear power would benefit the environment and public. Although there is not a strong correlation between the dependent variable, CO_2 emissions (metric tons per capita) and the independent variable, electricity production as a percent of total from nuclear, the investigator believes as the need and desire for more clean energy emerges a strong relationship between the two variables could be seen with more time and more study.

The knowledge of lower emission producing energy options could greatly benefit the United States from an environmental and economic standpoint. Public administrators on the federal level will need to consider that as the need for nuclear power increases, so will the need for more uranium. The World Nuclear Association found that as more countries have mined for uranium, the world's supply has increased fifteen percent as of 2007 (World Nuclear Association, 2011). Although the supply has increased as of 2009, the United States has access to only four percent of the world's uranium in sharp contrast to Australia, which has the largest percent in the world at thirty-one percent (World Nuclear Association, 2011). Legislators must consider the costs of importing uranium as the country's supply decreases and decide if the alternative of reprocessing would be beneficial. It is the belief of the investigator that reprocessing nuclear waste is the best alternative for the simple fact when spent nuclear fuel is reprocessed through the PUREX process, close to ninety-five percent of original uranium is available for reuse (Bunn et al., 2003). Not only would reprocessing benefit the country as a whole, but South Carolina would directly benefit environmentally and economically by significantly reducing the amount of nuclear waste being stored in facilities such as the one in Barnwell. The transition to reprocessing would not only benefit the environment by utilizing a more clean form of energy and reducing stored waste, but it would also provide the opportunity for job creation through the construction of new plants and employees to staff the plants.

Although the main hypothesis was not supported, this study can provide a base of knowledge for legislators to help explain the impact of CO_2 emissions and the use of nuclear power. The information found from this study could have direct implications on the research used to help drive energy reform, in pushing toward using more nuclear power and the reprocessing of spent nuclear fuel in the United States through a form of reprocessing such as

PUREX. Recently the issue of nuclear waste storage has been in the forefront of the media due to the current lawsuits against several government agencies creating an air of skepticism among Americans. This skepticism will force legislators on the federal and state level to support the grassroots movement of increasing the use of nuclear power. As found in the study conducted by MIT, most Americans are doubtful of nuclear power and the safe storage of waste and with good reason based on the history of nuclear power with the Three Mile Island accident, the Chernobyl disaster, and most recently the nuclear crisis caused by the tsunami in Japan. Just as lessons were learned from Hurricane Katrina, public administrators will need to gain the trust of their constituents and show lessons can be learned from every mishap. It is the belief of the investigator that if the economic and environmental aspects of increasing the usage of nuclear power and transitioning to the use of the PUREX process were explained to the American people in non-technical language, it would ease the fear of the unknown and would be widely supported.

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Appendix A: Electricity Production & CO_2 Emissions: ANOVA Results

Figure A1: Electricity Production from Coal by Country

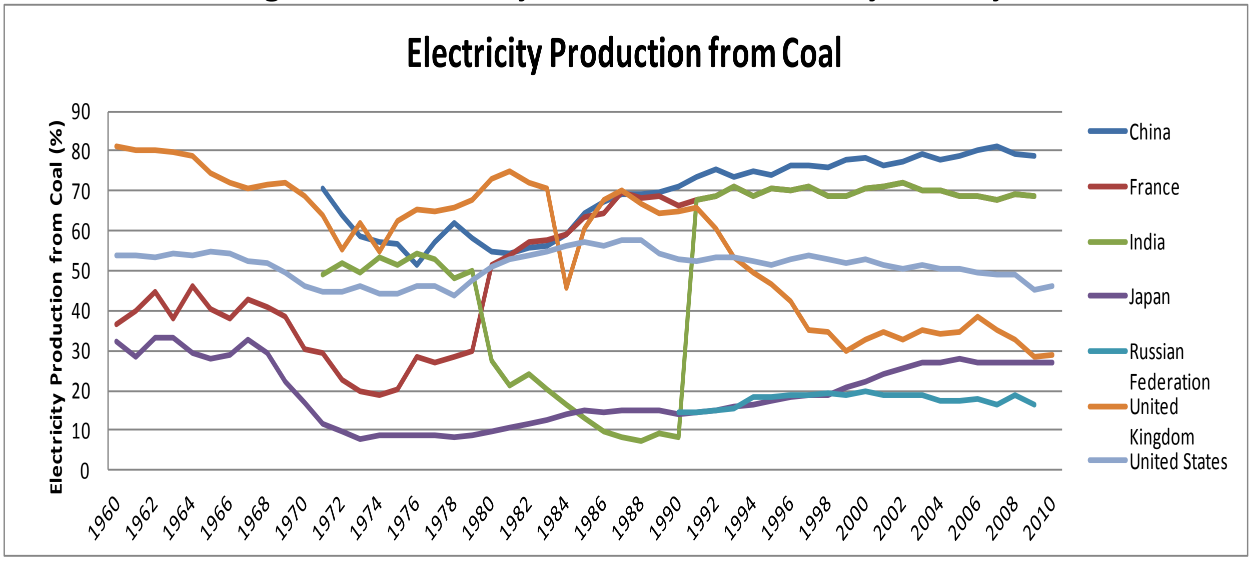


Table A1: Electricity Production from Coal % of Total

Level		Mean
China	A	69
United Kingdom	B	57.03
France	B	53.29
United States	B	51.22
India	B	49.99
Japan	C	19.38
Russia Federation	C	17.65

Figure A2: Electricity Production from Hydroelectric by Country

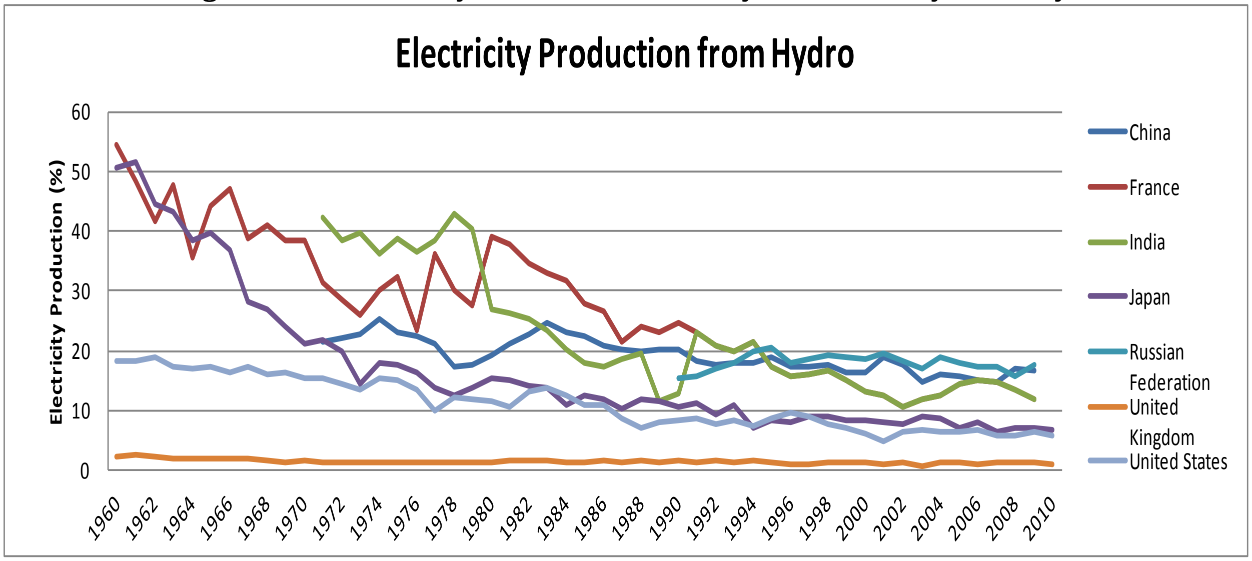


Table A2: Electricity Production from Hydro % of Total

Level		Mean
France	A	27.28
India	A B	22.36
China	B C	19.30
Russian Federation	B C	18.03
Japan	C	16.85
United States	D	11.20
United Kingdom	E	1.51

Figure A3: Electricity Production from Natural Gas by Country

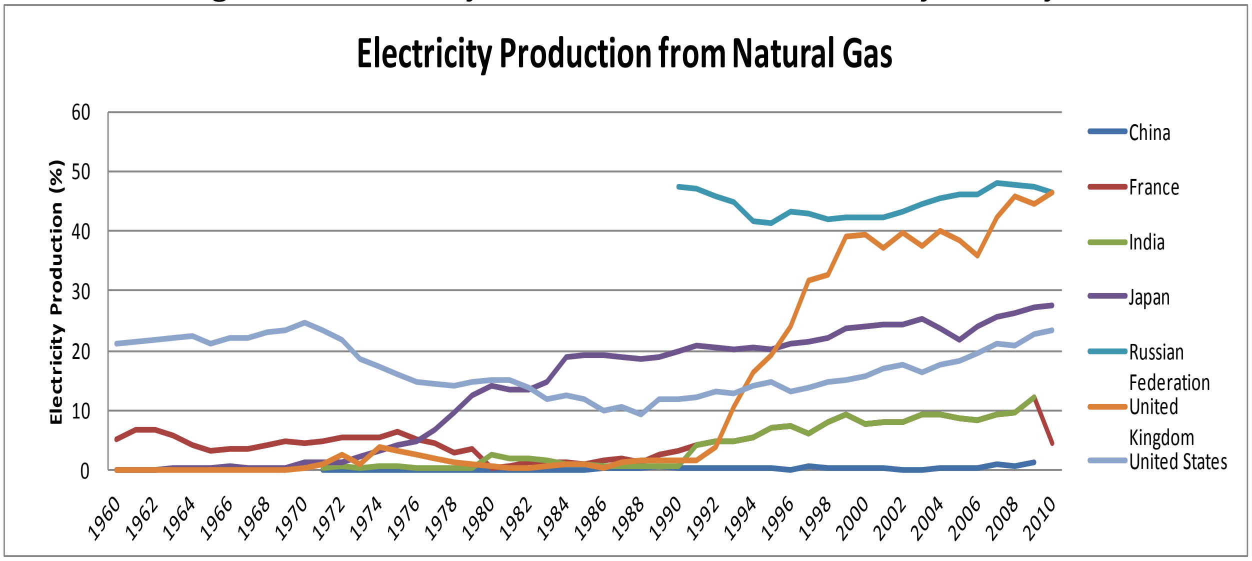


Table A3: Electricity Production from Natural Gas % of Total

Level		Mean
Russian Federation	A	44.65
United States	B	17.08
Japan	B	13.88
United Kingdom	B	12.89
France	C	5.27
India	C	4.30
China	C	0.33

Figure A4: Electricity Production from Nuclear by Country

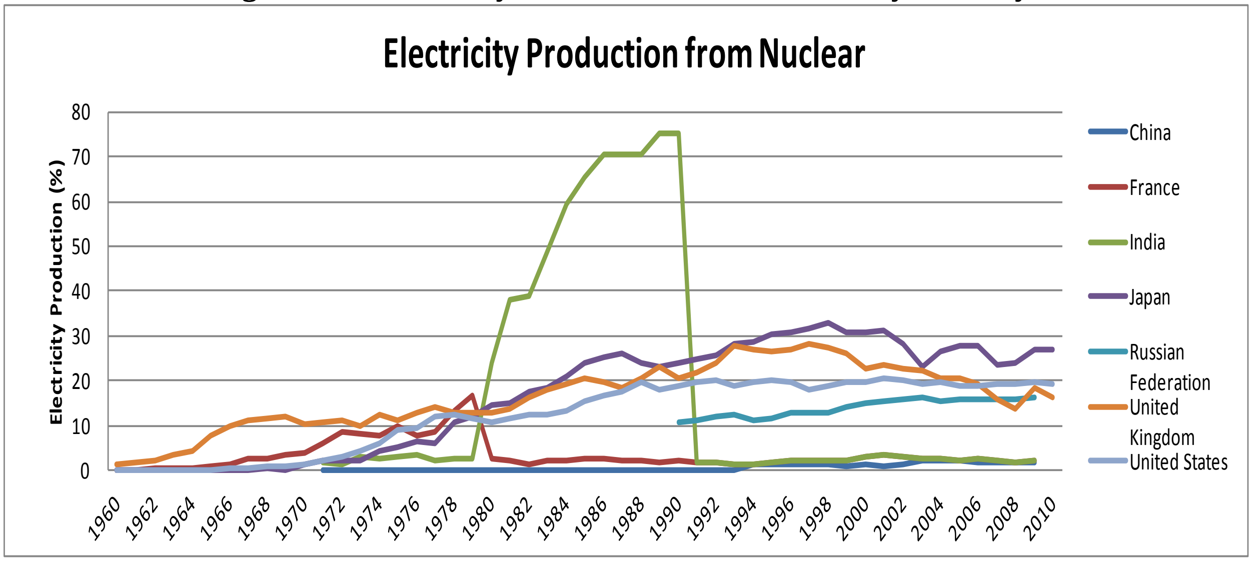


Table A4: Electricity Production from Nuclear % of Total

Level		Mean
India	A	18.05
Japan	A	16.62
United Kingdom	A	16.51
Russian Federation	A	14.00
United States	A	12.47
France	B	3.45
China	B	0.68

Figure A5: Electricity Production from Oil by Country

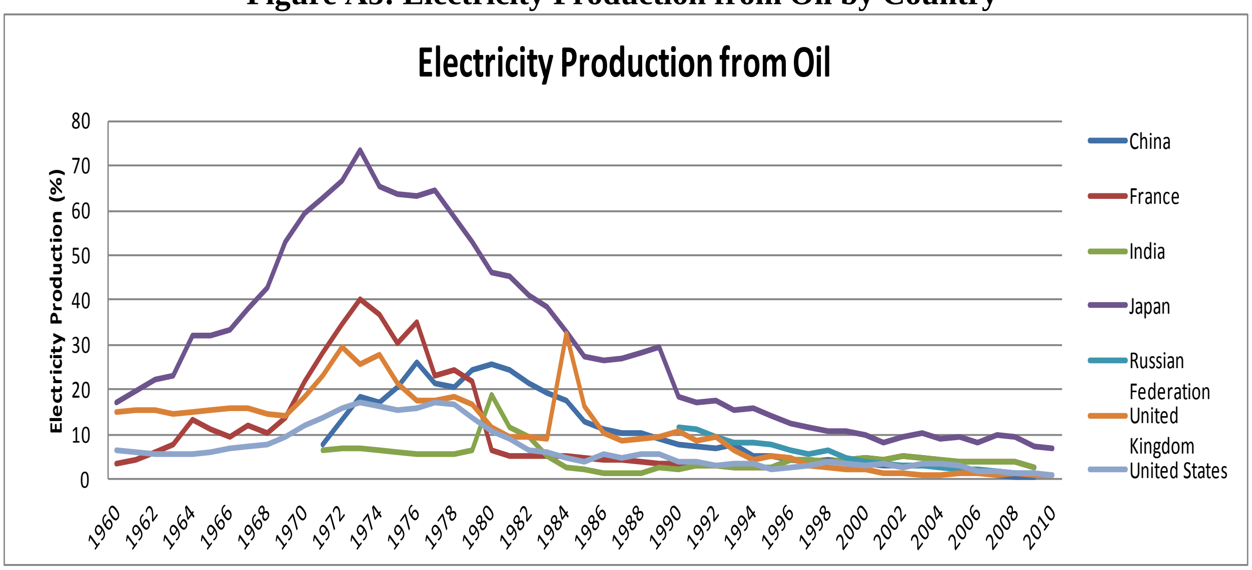


Table A5: Electricity Production from Oil % of Total

Level		Mean
Japan	A	30.01
United Kingdom	B	11.13
China	B	10.58
France	B	10.30
United States	B	6.79
Russian Federation	B	5.27
India	B	4.87

Figure A6: Electricity Production from Renewable by Country

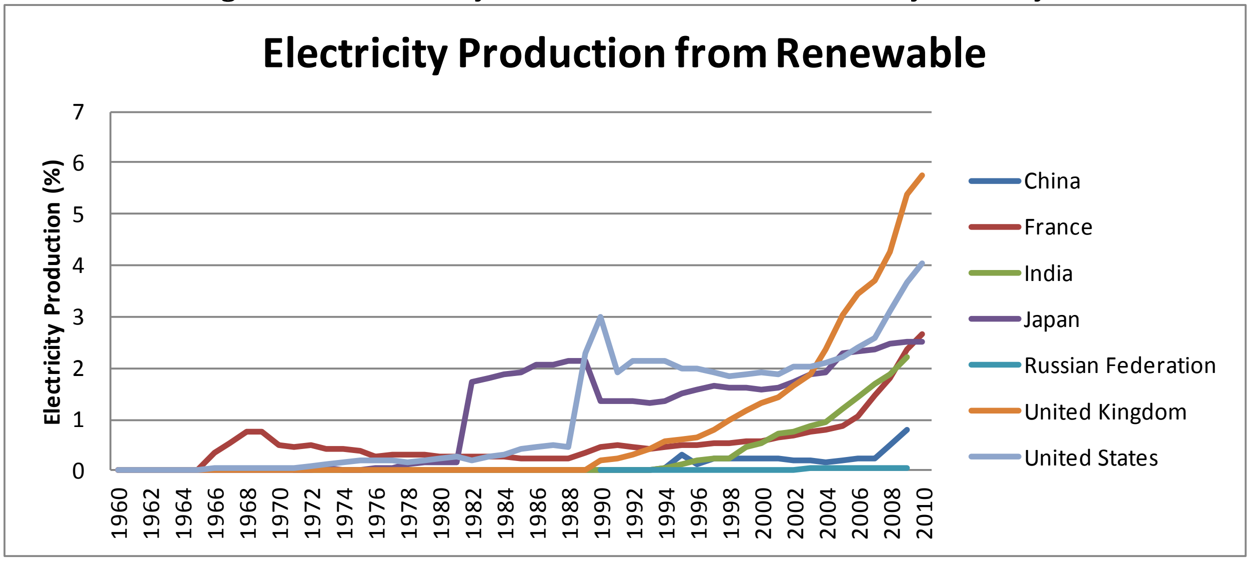


Table A6: Electricity Production from Renewable % of Total

Level		Mean
United States	A	1.10
Japan	A B	1.07
United Kingdom	A B C	0.79
France	B C D	0.54
India	C D	0.35
China	D	0.11
Russian Federation	D	0.02

Figure A7: Total CO_2 Emissions by Country

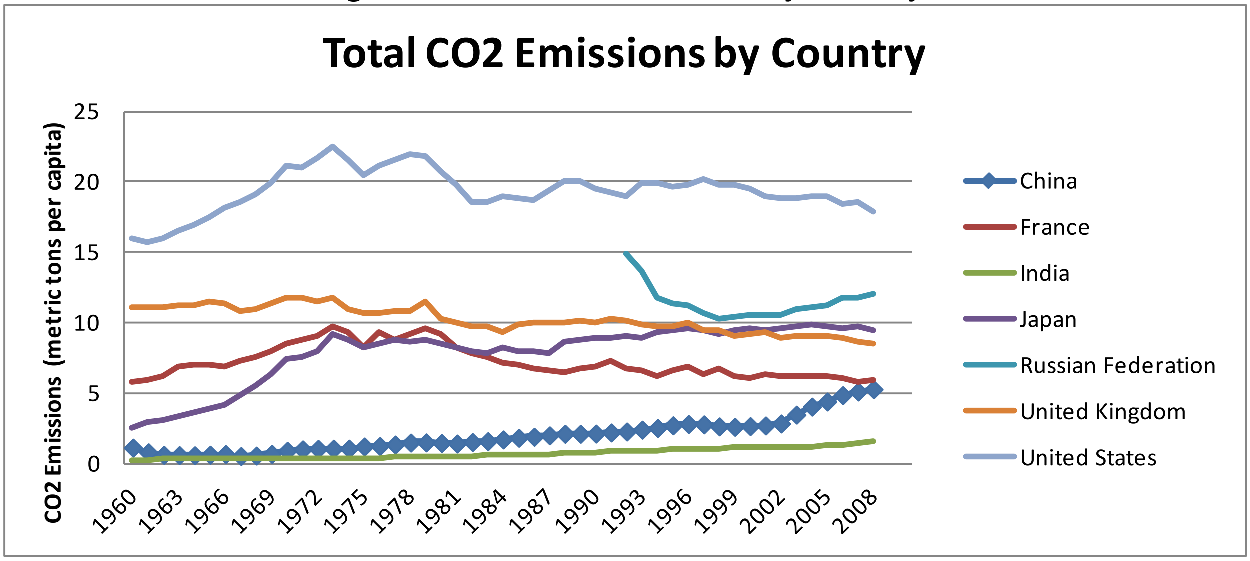


Table A7: ANOVA results CO_2 emissions

Level		Mean
United States	A	19.35
Russian Federation	B	11.49
United Kingdom	C	10.25
Japan	D	7.87
France	D	7.24
China	E	2.01
India	F	0.71

Appendix B: kWh by CO$_2$ Emissions

Figure B1: China: kWh by CO$_2$

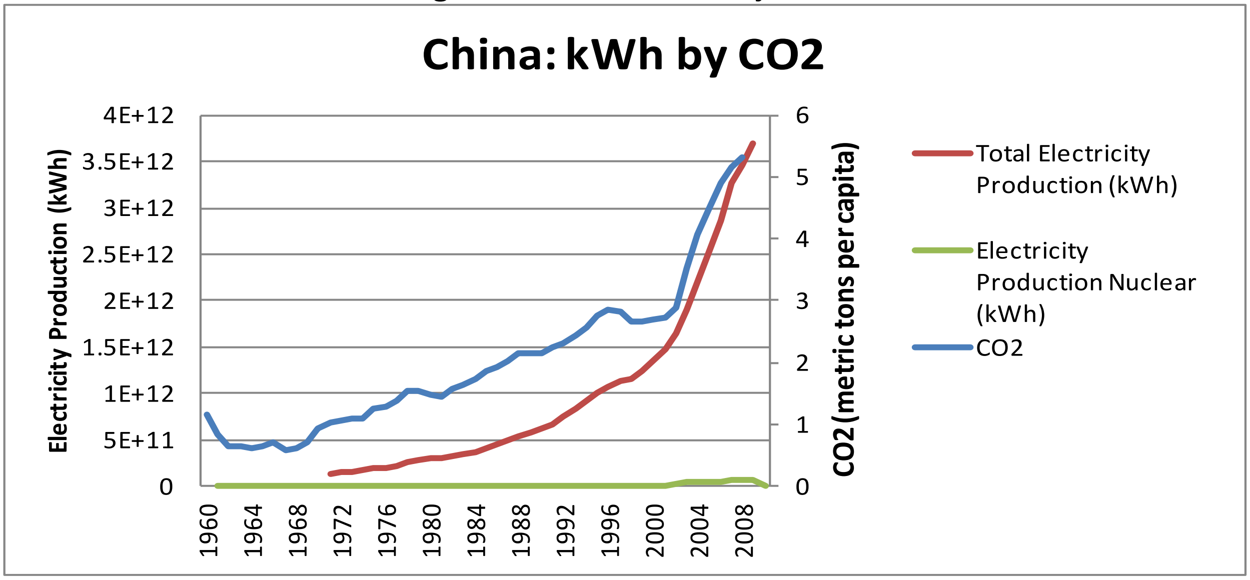


Figure B2: France: kWh by CO$_2$

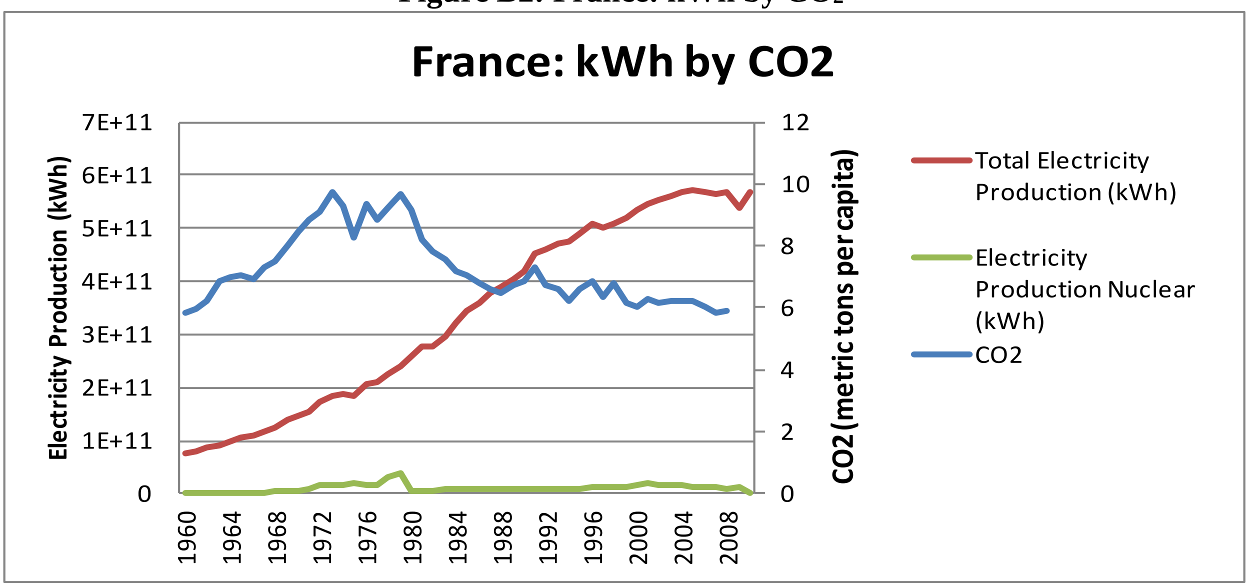


Figure B3: India: kWh by CO_2

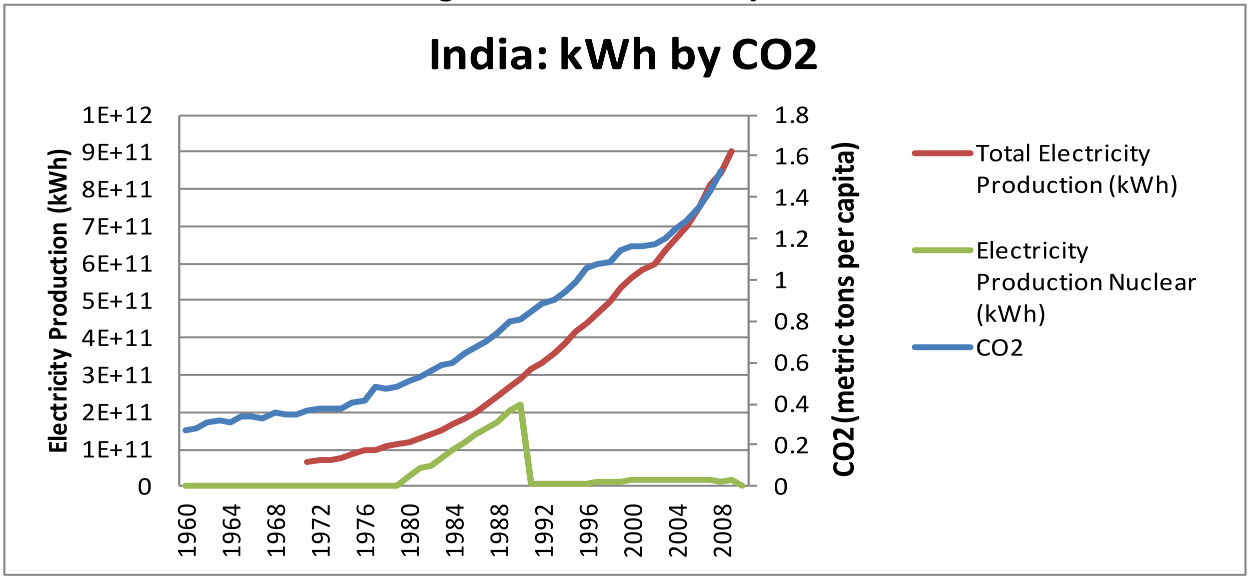


Figure B4: Japan: kWh by CO_2

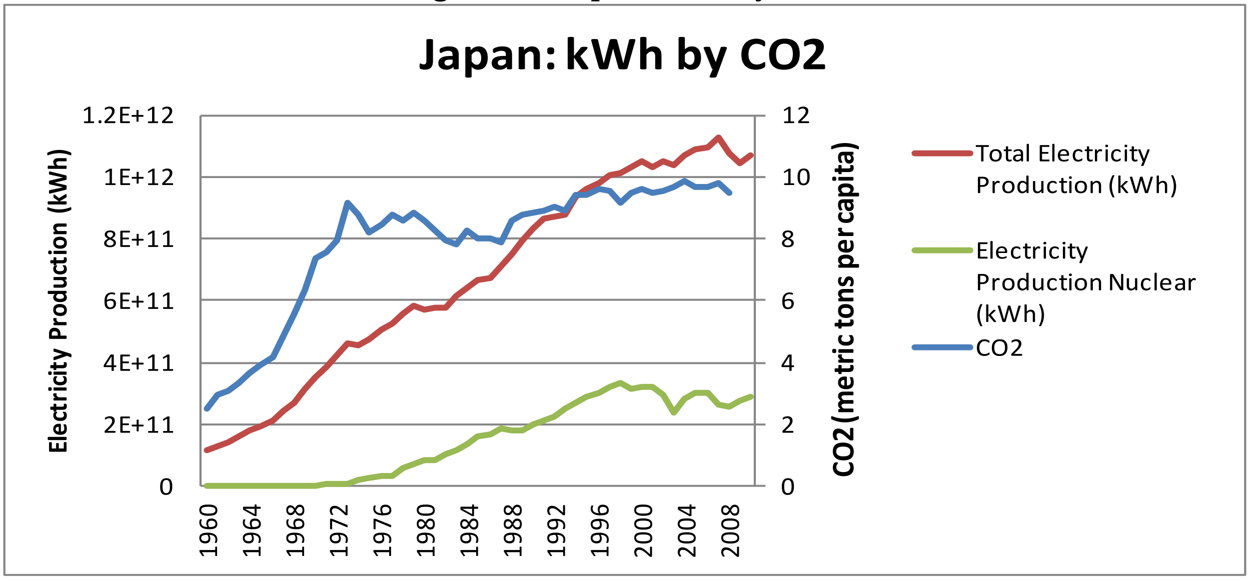


Figure B5: Russia: kWh by CO_2

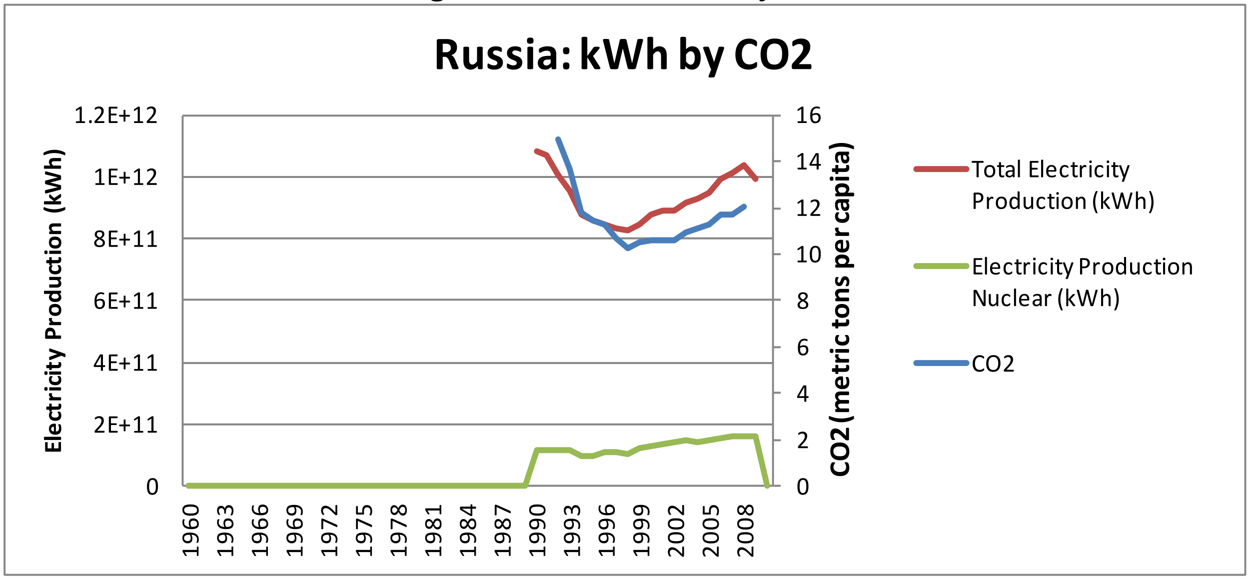
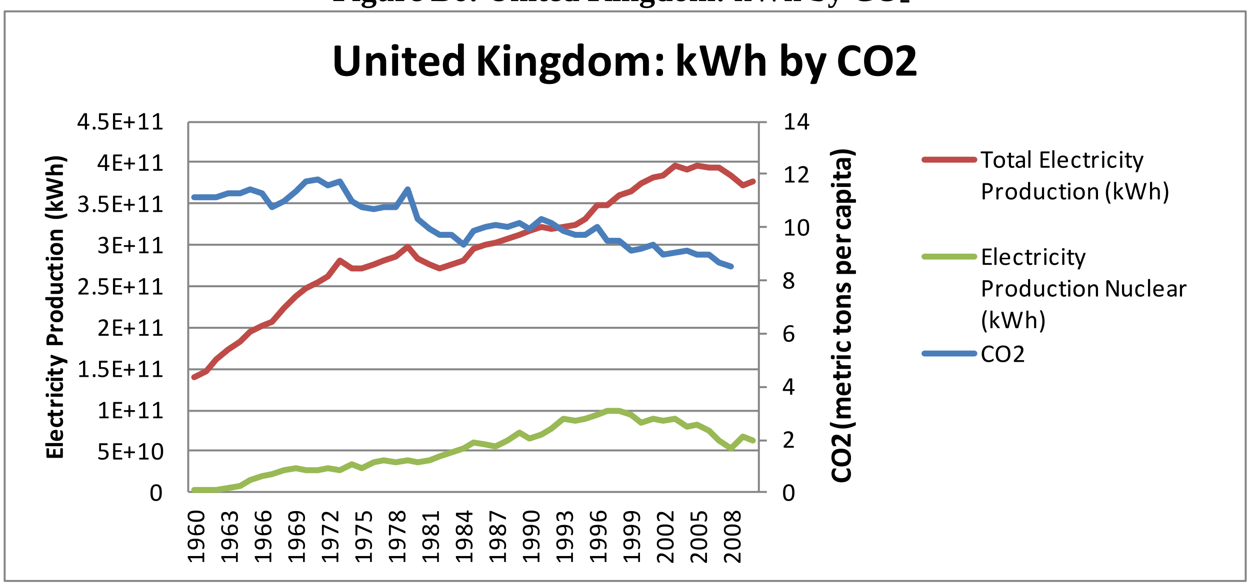


Figure B6: United Kingdom: kWh by CO_2



Appendix C: Electricity Production Mix by Country

Figure C1: China: Electricity Production

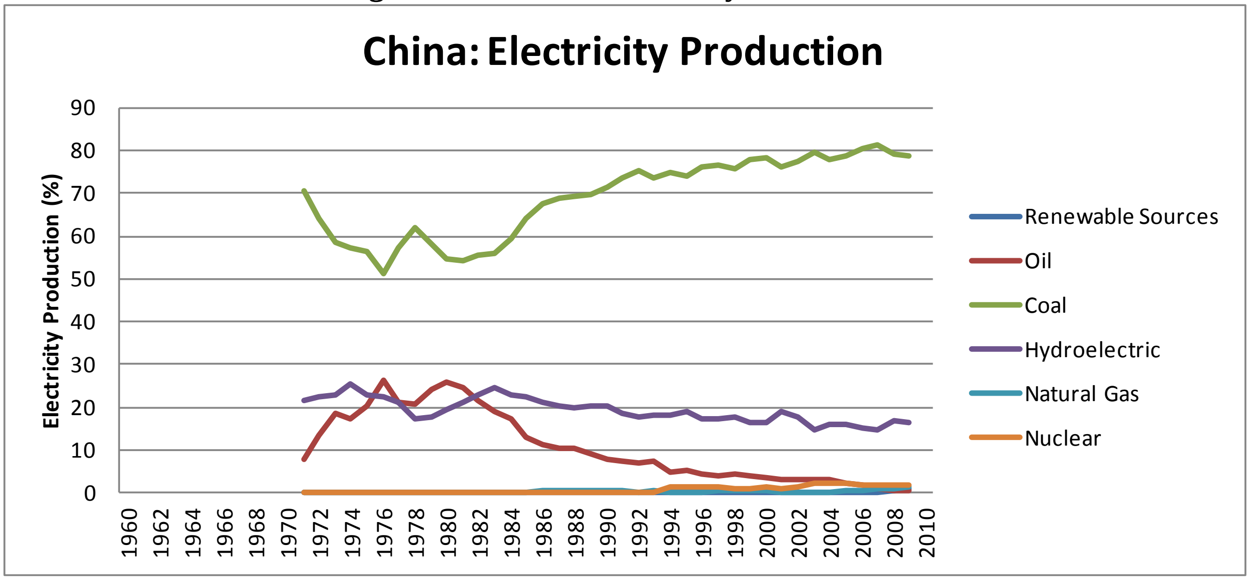


Figure C2: France: Electricity Production

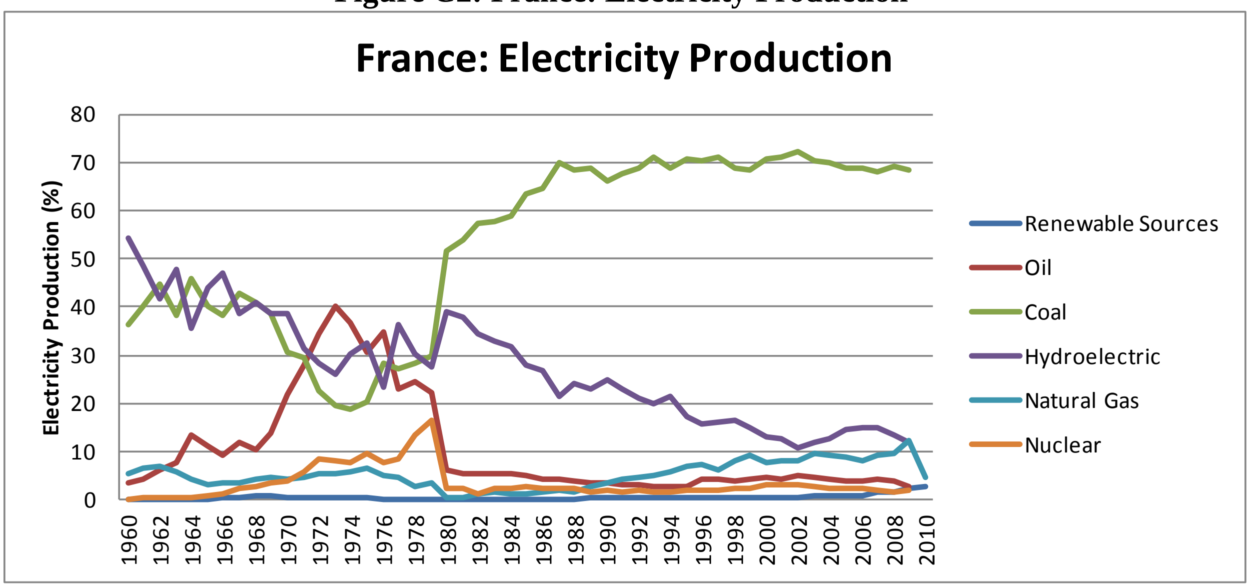


Figure C3: India: Electricity Production

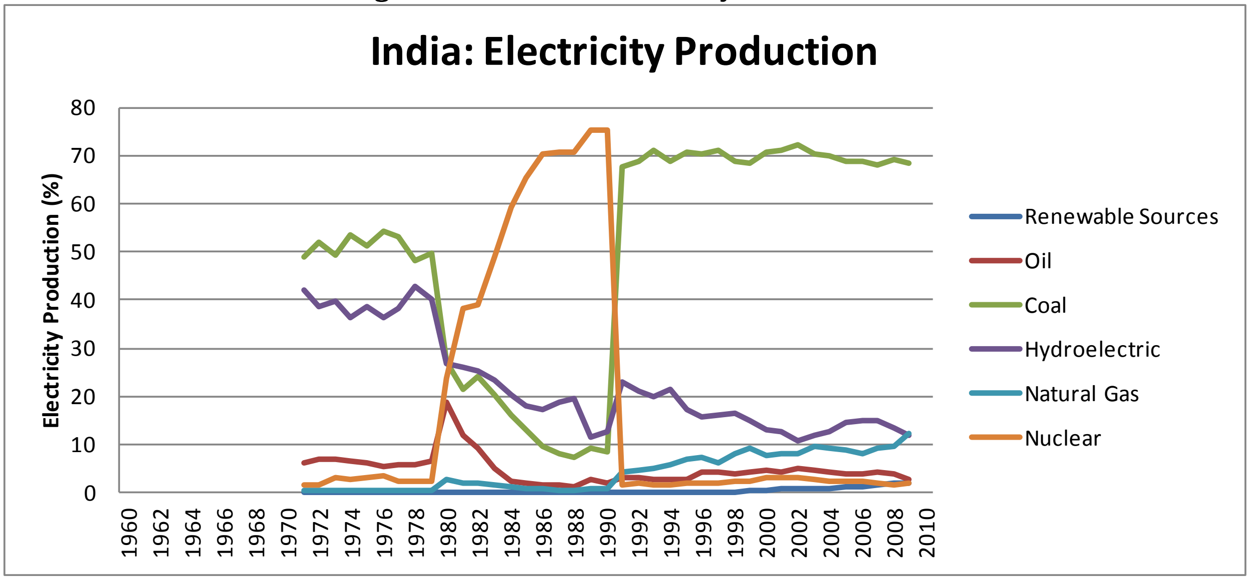


Figure C4: Japan: Electricity Production

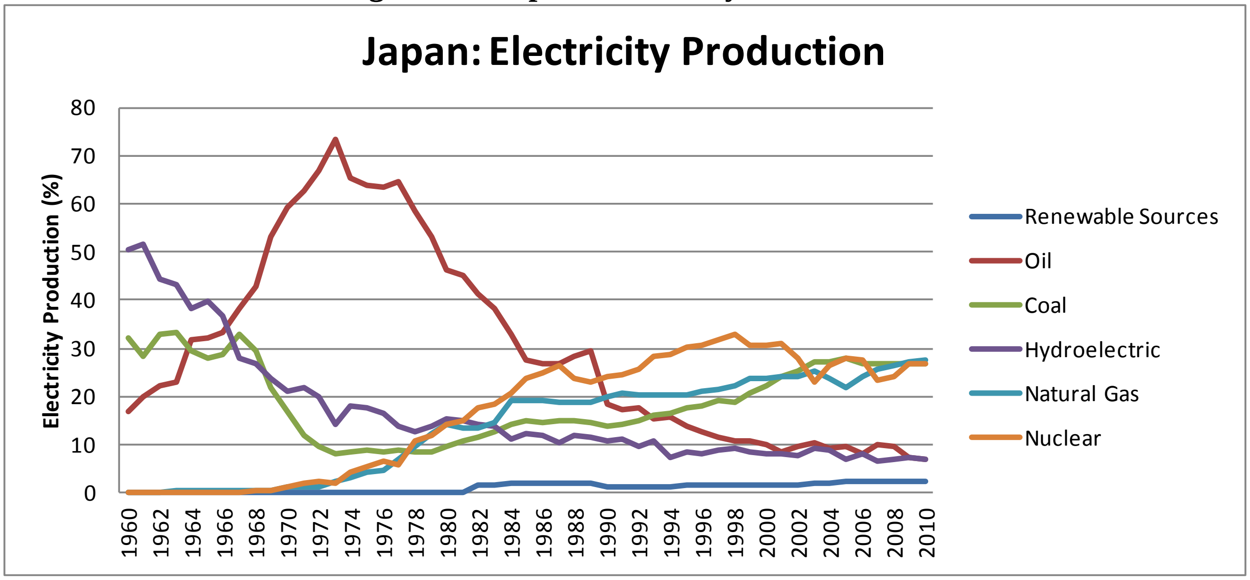


Figure C5: Russia: Electricity Production

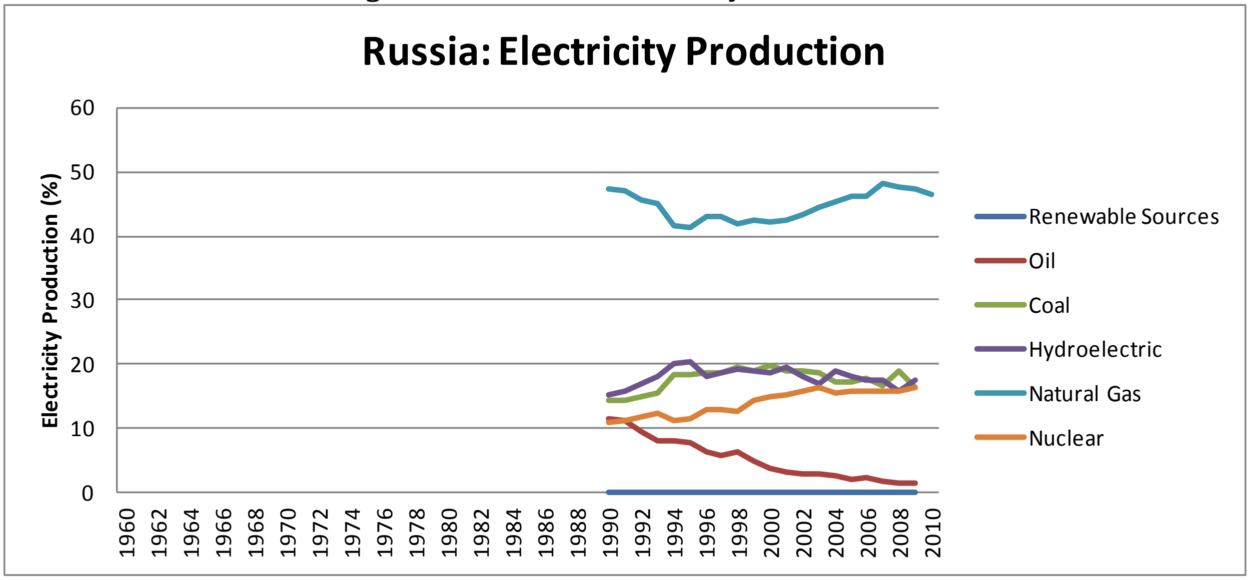


Figure C6: United Kingdom: Electricity Production

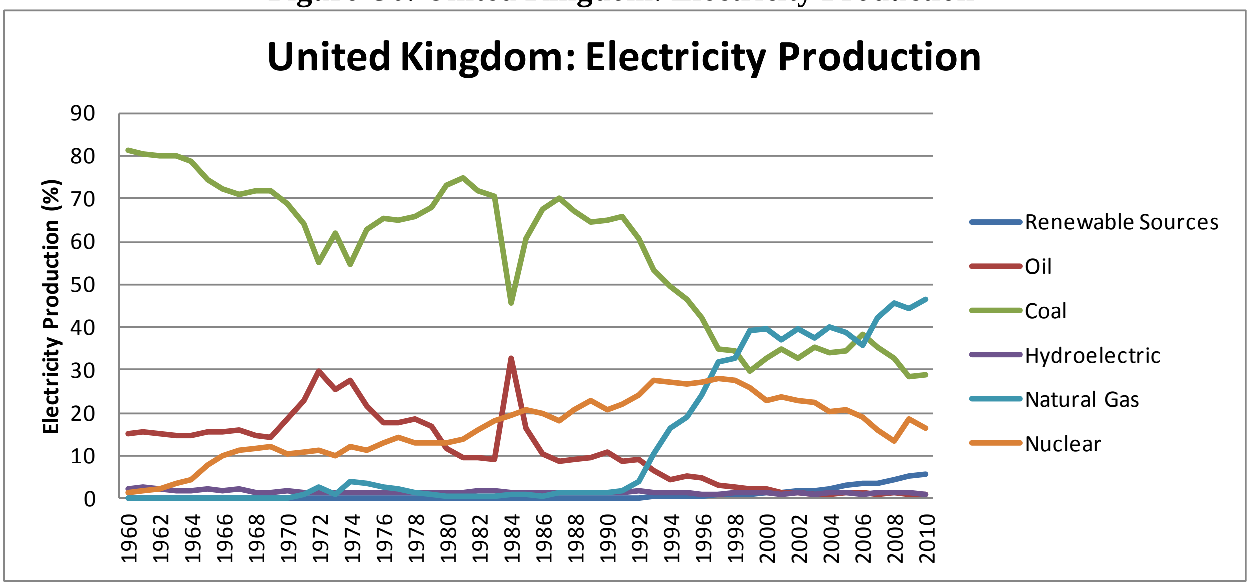


Figure C7: United States: Electricity Production