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Nuclear Power Plant Policy Comparison between the U.S. and Republic of Korea

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Nuclear Power Plant Policy Comparison between the U.S. and Republic of Korea: Existing and emerging policies to support nuclear and nuclear power costs

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ABSTRACT

Five years after the Fukushima accident, people and countries still argue about the opportunity costs of denuclearization. While nuclear power generation has safety and waste issues, it is carbon free. Climate change has created more pressure for greenhouse gas reduction, so a few countries have decided to maintain or even increase nuclear power generation. The United States ranks first for using nuclear power produced by electricity generation, while the Republic of Korea, the closest country in proximity to Japan, ranks fourth in countries that use nuclear power. In fact, Korea even rapidly increased nuclear business after the Fukushima accident. Despite great health risks and waste problems, why use nuclear? Through analysis and comparison of key energy policies that support nuclear and nuclear costs in these two countries, this research paper seeks to determine the reasons behind the usage of nuclear power.

ACADEMIC HISTORY

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1. Introduction

Opinions about nuclear power have been clearly divided into two polarized reactions, which are to either increase nuclear power or denuclearize completely. Each claim has been argued so much that their arguments have become clichéd. People who are against nuclear power provide reasons of risks, and those who support it often say nuclear power cannot be replaced by other renewables in terms of coping with a new era of climate change. Although these two sides seem to have no neutral ground to discuss nuclear power and narrow the gap in opinion, there is actually a covered and clear matching point.

Economic analysis was not applicable until the Fukushima accident happened. Fukushima dai-ichi accident became a perfect case study of how much nuclear power business will suffer if nuclear power plants explode or nuclear wastes are emitted. As a result, many countries that used to support nuclear power, considering it as a future alternative power, turned away from nuclear power and decided to close nuclear power plants. However, there are some countries that still believe in the miracle of nuclear power and continue to install new nuclear power plants. Ironically, the Republic of Korea, which is the closest country to Japan, is proud of its nuclear technologies and has decided to add four more reactors to its existing fleet of 24. Ahead of Korea's nuclear power and nuclear power technology development is the United States, the world's top nuclear producing country.

The objective of this research is to examine the actual purposes of the nuclear power business in each country and to evaluate the economic costs of nuclear power.

This research paper analyzes policies from the two countries to determine what factors led them to support nuclear power generation, and how the actual nuclear costs and the costs in the Levelized Cost of Electricity are different. The paper also analyzes the missing and overlooked factors in the policies, which become apparent if there are big gaps between the projected and actual costs. Since the United States and the Republic of Korea have different social and political structures, this paper focuses more on the common factors and policies for comparison.

This paper is organized into two halves. The first addresses the questions: What are the major policies supporting nuclear power generation, and what is the main purpose of the increased nuclear power? The questions will be answered with analysis of key energy policies and nuclear-related policies.

The second half addresses the question: How have nuclear power costs been estimated, and what factors have been overlooked? This part will analyze the nuclear costs with comparison between actual costs, costs stated in policies, and the Levelized Costs of Electricity (LCOE) report. The LCOE is a measure of power, which is the net present value of the unit cost electricity overtime. The Organizations for Economic Co-operation and Development (OECD) reports are used since they not only provide these two countries' data, but also allow for comparison to data from other countries.. The hypothesis of this research paper is that the actual nuclear cost has not been well reflected into the Levelized Cost of Electricity, resulting in a cost-benefit analysis of nuclear power that is not fairly evaluated.

2. Background

2.1. Advantages and concerns

2.1.1. Advantages

An advantage to nuclear power is that it is a stable energy source. Conversely, oil deposits in the world are limited and about to show their end (Heinberg, 2015). The unstable oil prices have caused fluctuation in the world economy, and oil has even caused international conflicts. According to World Energy Outlook by the International Energy Agency, the world energy demand in 2035 will increase by about 33% compared to demand in 2011, due to population growth (WEO, 2013). Since the demand for energy is steadily increasing, a stable energy supply is an important factor of a stable world economy. While the oil deposits seems to be depleted, the Uranium nuclear relies on is still plentiful in the world. The projected Uranium deposits in the world will cover energy demand without reprocessing until 2050 (NEO, 2008). 14% of the total world energy production is already from nuclear power now, and it will take on an important role in energy security (Lee, 2011).

Moreover, as climate change becomes a major challenge for global society, the fact that nuclear power does not emit Greenhouse Gases (GHGs) through generation makes it viable as a future energy source, and a climate change mitigation strategy. In fact, world CO_2 emissions would increase by 10% more if there were no nuclear power plants (Lee, 2011). Although nuclear emits CO_2 in the process of uranium excavation, it emits far less GHGs compared to other traditional energy sources (Kimble, 2011).

In addition, there are low fuel costs for nuclear compared to other fossil fuels. The Levelized Cost of Electricity for coal generation is around $75/MWh, while for nuclear generation it is only approximately $29/MWh at 3% discount rate in Korea. Although the costs in the U.S. are higher than in Korea, coal fired power generation costs around $83/MWh, and nuclear is much lower at around $54/MWh (NEA, 2015). As the science and technology developed during World War I and II, nuclear power has risen as a future energy source with extraordinarily explosive power within a small mass. The rate of fuel cost in the total nuclear generation cost in Korea is only 10.2% while the rate of oil is 78% (WIIN, 2015). The low nuclear fuel costs are "steadily increasing efficiency and cost reduction (World Nuclear Association, 2015)".

2.1.2. Concerns

The biggest concern for nuclear power is the potential health impact. It could not only lead to disastrous consequences when an accident occurs, but could also cause cancer to the people near the reactors. The Three-mile island, Chernobyl, and Fukushima accidents show how nuclear power can be dangerous and expensive. While the Three Mile Island accident released a small amount of radiation when part of the core was melted down in the number two reactors, the Chernobyl and Fukushima accidents released a great amount of radiation. In Japan, 160,000 people were evacuated from the 20-30 km evacuation zone after radiation contamination of Fukushima nuclear reactors. The evacuation zones become infertile land and will not be recovered almost forever. These radiation evacuees constitute 47% of total evacuees from the 2011 Tsunami and nuclear accident (Hasegawa, 2013). The total cost of the

Fukushima disaster will come to more than $105 billion, which is twice the earlier estimate (RT, 2014). Despite evacuation, the four years of radiation exposure seem to be related to thyroid cancer based on results from a study on the health risks of Fukushima residents 18 years old and younger. This study shows the increase of thyroid cancer detection in Fukushima area after the nuclear accident (Tsuda, 2015). The Korean court also reached a verdict that the operators of the Kori reactors should compensate residents who had cancer. This judge recognizes that the nuclear power causes cancer and threatens public health (Kwon, 2014).

Waste management is expensive, difficult, and time-consuming. While nuclear power generation does not emit CO2, it leaves radioactive wastes, which can be a more serious health and economic problem than emitting greenhouse gases. The total accumulated spent nuclear fuel assemblies in the United States "would only cover a football field about 5 1/2 yards high (NRC, 2002)." However, this small amount of waste is considered the most dangerous product in the world. There are many kinds of radioactive materials in nuclear wastes, and four materials are directly related to human health problems: Cesium137, Strontium90, Radium, and Uranium238. Cesium137 and Strontium90 are the most dangerous chemicals if they come into contact with the human body. They cause cancers and hereditary diseases, but have a relatively shorter half-life of around 30 years. Radium has a much longer half-life around 1600 years, and is less dangerous though it causes anemia and osteomyelitis (World Nuclear Association, 2015). Although Radium has a long half-life, Uranium238's half-life is incomparable. It is 4.5 billion years, which is as long as Earth has been in existence

(World Nuclear Association, 2015). Consequently, these highly dangerous radioactive materials must be sealed away from the outside world forever.

Although radioactive materials are isolated to prevent human contact, they can contaminate the environment and ecosystems. This eventually leads back to humans at the top of the food chain, especially since the human body can be both internally and externally exposed to radiation. If a human is internally exposed through inhalation, skin contact, and digestion of radioactive materials, the materials will accumulate and keep biological atomic collapsing in the human body. Though there are three types of radiation — alpha, beta, and gamma radiation—the gamma ray is the only one that can externally penetrate. However, when the nuclear materials are integrated into the human body, the alpha and beta particles "increase the cancer risks at several anatomical sites (Ghisassi, 2009)." This collapsing manipulates human DNA, and will therefore effect future generations (Wessells, 2012). So, nuclear waste that has been disposed of needs to be protected forever, but there is currently no technology for forever disposal without leakage.

While nuclear power has the incentive of cheap fuel costs, its capital costs are comparably higher than any other power sources since it requires advanced technology and a long installation period. The capital costs include the bare plant cost, the owner's costs, cost escalation, and inflation (WNA, 2015). The overnight costs are often used to compare, and simplify cost by excluding discount or interest rates. The overnight cost of nuclear has been increasing since the 1990s (NEA, 2015). The actual construction costs are often double the projected costs due to the inflation, discount rate, and interest rates (Song, 2015). This paper will discuss these costs more in depth in Section 5 on nuclear power costs.

2.2. The World after Fukushima

The world has been divided into two sides after Fukushima. On one side are countries that have decided to stop running nuclear power plants or not build additional nuclear power plants. On the other are countries that have maintained the attitude that an accident like Fukushima will never happen in their country. Among these are nations that have even taken measures to increase their share of nuclear power in order to reduce carbon emissions.

Anti-nuclear activity has actively occurred in Germany since 1980, however, and Germany shows the most significant changes in nuclear policy after the Fukushima accident (Polman, 2011). The German government has stopped 9 of 17 nuclear power plants and will stop rest of the plants by 2022 (Lee, Shin, Shin, 2015). This is despite the fact that nuclear power was 10.9% of total German energy, and 33.6% of the German electricity mix in 2010 (Polman, 2011). Although nuclear power had a great role, denuclearization has not greatly influenced electricity prices in 2015. According to Harry Lehmann, the head of the division of “Environmental Planning and Sustainable Strategies” within the German Federal Environment Agency, denuclearization and renewable energy development have not caused the raises in household electricity prices that have been occurring since 2010 (Polman, 2011). Moreover, Germany still exports energy, in spite of concerns over a possible lack of energy supply after stopping the nuclear power plants. The government has replaced nuclear power with higher energy efficiency and a transition to the renewable energy (Lee, Shin, Shin, 2015).

2.3. Nuclear power in the United States

The United States is the second biggest CO2 emitter in the world, and the top country for nuclear power. In 2013, the energy sector produced 5,636.6 million metric tons of CO_2 equivalent emissions, which is around 90% of total emissions in the U.S. Electricity accounts for 37% of total CO_2 emissions in the U.S. (EPA, 2015). Total electricity net generation in the U.S. is 4,048 billion kilowatt-hours in 2012, and nuclear power generates about 20% of the total, which was 797.1 billion kilowatt-hours in 2014 (EIA, 2012; NEI). Additionally, around 9.5% of total primary energy production in the U.S. is from nuclear electricity power (EIA, 2014). Currently, 99 licensed nuclear reactors in 61 commercial plants are operating in the United States. The oldest operating reactor is Oyster Creek in New Jersey, whose license was issued in 1969, and the newest reactor is Watts Bar 1 in Tennessee, which has been in operation since 1996. Five more reactors are under construction, and additional reactors are under consideration or have already been licensed (NEI website). 19 new reactor applications are under review (NRC, 2015). Nuclear capacity in the United States rapidly increased during the 1970s and 1980s before it stabilized in the 1990's. Although some reactors have been decommissioned, the nuclear capacity will stay at approximately the same level due to the new reactors' installation (EIA, 2015). However, half of the nuclear reactors are currently over 30 years old and need to be closed soon, which means that around 50 new advanced nuclear reactors should be built to maintain the capacity (Hargreaves, 2011).

Although the nuclear power industry faces the challenge of high costs, the government supports nuclear power as a way to reduce Greenhouse Gases. Nuclear power in the U.S. prevented 289-429 million metric tons of CO_2 emissions and other air pollutants, such as sulfur dioxide and nitrogen oxide, from being released into the atmosphere in 2014 (NEI, 2014). The main appeal and key words for nuclear energy on governmental organizations' websites are "carbon-free energy (NEI, NRC, and KHNP websites)."

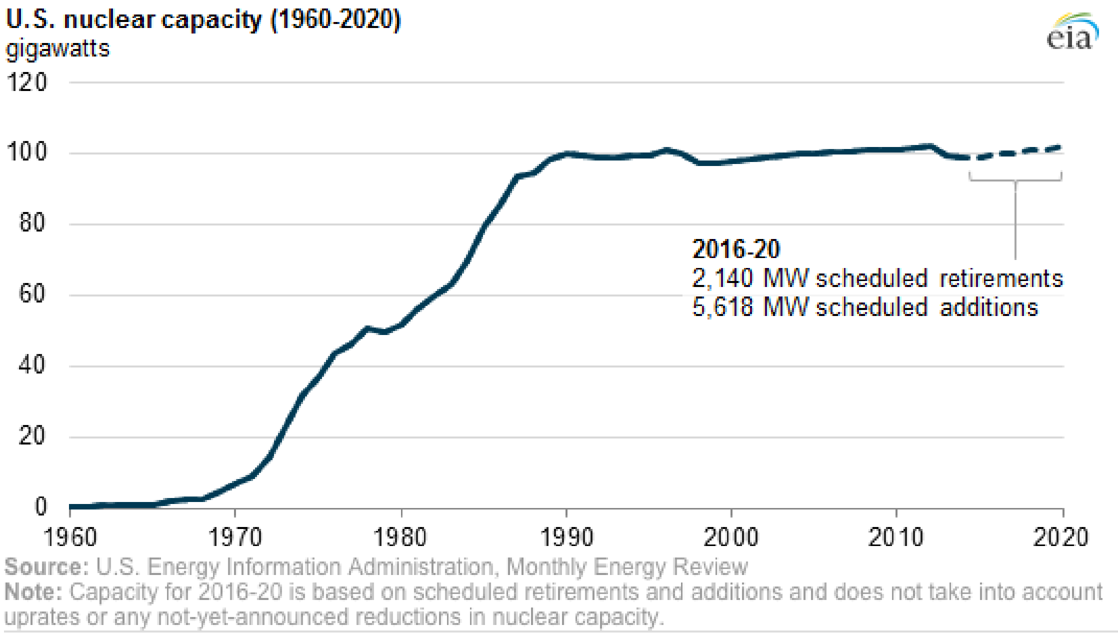

Figure 1 the U.S. Nuclear Capacity 1960-2020 (EIA, 2015)

As shown in Figure 1, the nuclear capacity in the U.S. has rapidly increased since the early 1970s, and it became stable around the 1990s. The decommissioning causes little changes in the 2000s. This means most nuclear reactors were built in the 1970s, and the reactors are now around 40 years old. The EIA projects that the new reactors will be added to recover the retirements.

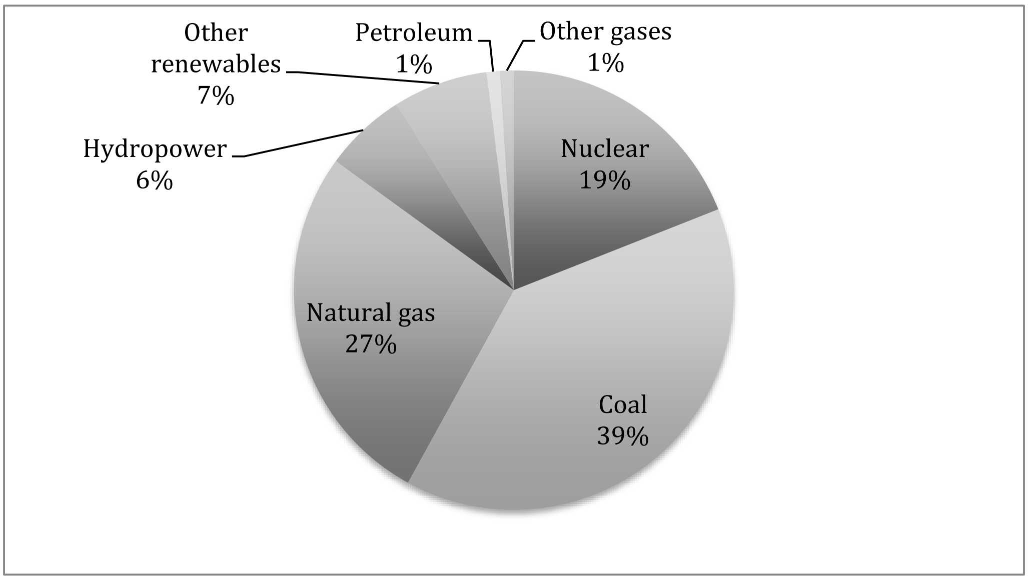

Figure 2 Electricity Generation by Energy Source in 2014 (EIA, 2015)

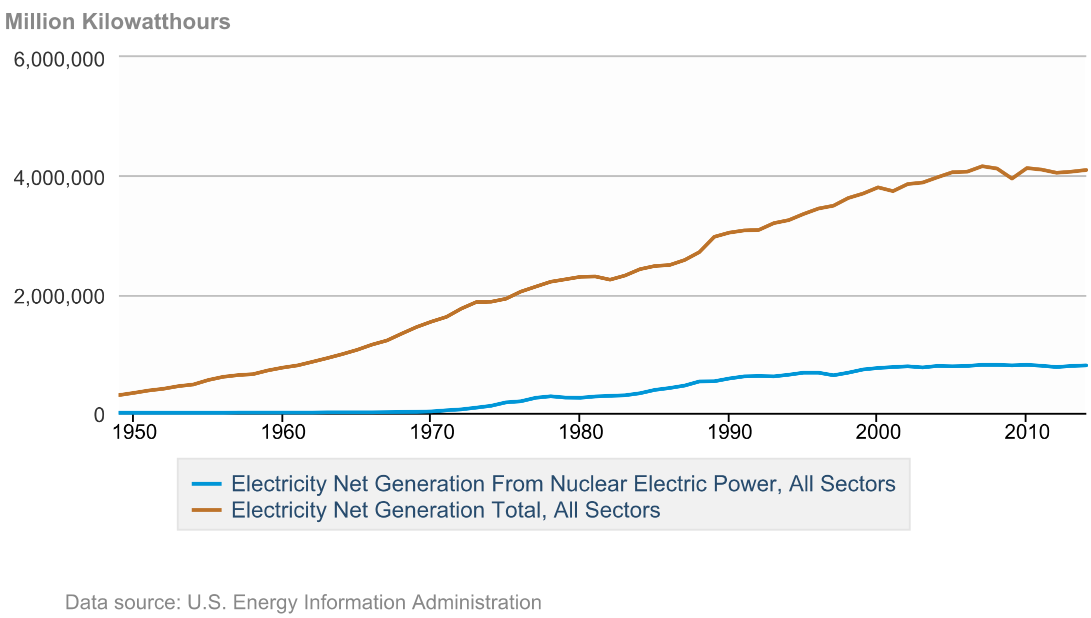

Figure 3 Electricity Net Generation: Total (all sectors) and nuclear power (EIA, 2015)

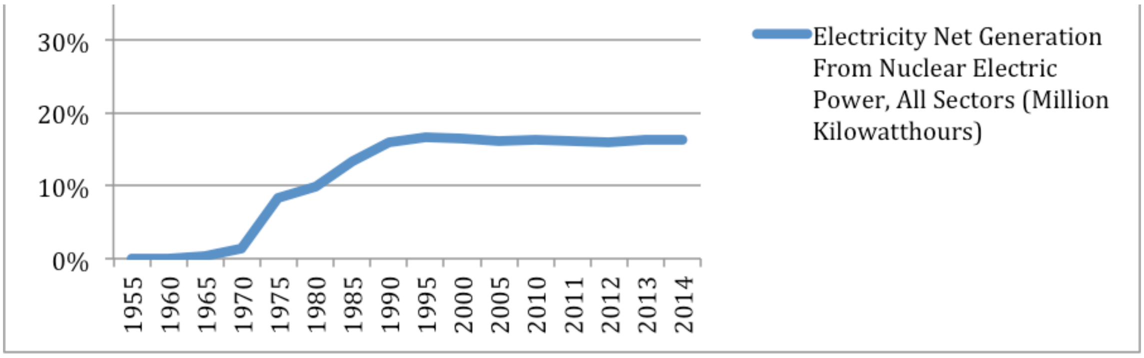

Figure 4 Electricity Net Generation % of Nuclear Electricity Power

As shown in Figures 2, 3, and 4, nuclear power occupies around 20% of total electricity generation in the U.S. since 1990. Figures 1 and 4 show that as the nuclear capacity increases, so does the percent of nuclear electricity power. This assumes that only nuclear power capacity increases while other energy sources stay the same.

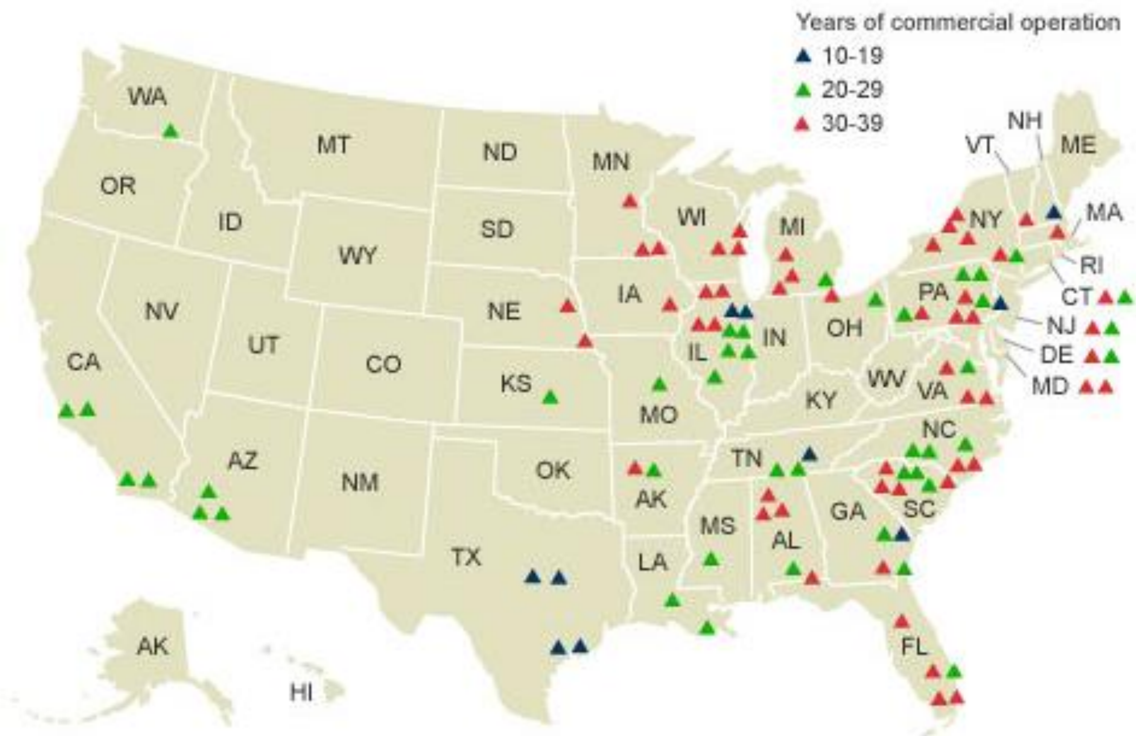

Figure 5 Age of nuclear power plants (Hargreaves., 2011)

Figure 5 shows that there are many nuclear power plants older than 40 years in the North and East parts of country, which are the most heavily populated. This means large populations are at risk from nuclear accidents.

2.4. Nuclear power in Republic of Korea

The Republic of Korea has been one of top ten emitters in the world, emitting 657 million metric tons of CO_2 equivalent in 2012. The total electricity net generation in the Republic of Korea is 500 billion kilowatt-hours (EIA, 2012). Korea is highly dependent on nuclear power generation, and 23 nuclear power plants generated 156,406GWh in 2014, which accounted for 30% of total energy production. Recently, the Shin-Walsung reactor has started to operate, so in total 24 nuclear reactors are licensed and operating. Moreover, two more new reactors at the Shin-Kori site and two at the Shin-Hanul site are under construction. Even without these sites in operation, Korea is the fourth ranked country for nuclear power by electricity output (Korea Hydro and Nuclear Power Corporation, KHNP, website).

Nuclear power plants in Korea significantly threaten national security, since Korea has the highest concentrated rate of nuclear power plants. The Republic of Korea has a small territory, which is similar to the size of Maine. In this small land, there are 24 nuclear reactors with high concentration. As Fukushima dai-ichi and dai-ni accidents prove, when one nuclear reactor has an accident, nearby reactors are exposed to great risks and could potentially explode as well. The Kori and Shin-Kori Plants now have 6 reactors, and the Korea Hydro and Nuclear Power corporation is in the process of licensing two more reactors at this plant. After these are built, the Kori and Shin-Kori plants site will be the world's highest concentrated nuclear reactor site, which poses a threat to Korean national security. The resident population in the 30 km evacuation zone is 3.4 million including the second biggest city in Korea (Greenpeace, 2015).

Moreover, although the Korean government has declared that nuclear power helps to reduce carbon emissions, Korea has achieved less progress in reducing carbon emissions than expected, and the least development of renewable energy compared to other OECD countries. The government was only attentive to increasing supply, but not managing demand, and as a result, there was inefficient energy use through over consumption and waste (Ministry of Trade, Industry, and Energy, 2014). Korea had been through blackouts, electricity shortages, and skyrocketing carbon emissions at the same time, in 2012 under the Lee administration. Since the increase of nuclear reactors and carbon emissions were directly proportional, it is doubtful that nuclear power generation really lowers the amount of carbon from society.

Unlike the United States, all Korean nuclear plants are operated by a state-owned company, KHNP, which follows directions from the government. The market does not determine electricity prices, but rather the government does. That is why the nuclear policies in the U.S. use the term "subsidies" in the nuclear industry, whereas Korean policies just use the word "increase" for nuclear power. KHNP makes contracts with the construction companies to install the nuclear power plants through a public contest. After the installation, KHNP operates all the plants and is responsible for the generating process.

Table 1 Overview of nuclear electricity in both countries (CIA, 2016)

	Absolute CO2 emissions in 2012 (EIA, 2015)	Per capita CO2 emissions in 2011 (World Bank, 2015)	Share of nuclear installed electricity generating in 2014 (EIA, 2015)	Total installed capacity in 2012 (CIA, 2015)	Total number of operating reactors in 2015	No. of reactors per km^2	No. of reactors under construction in 2015
United States	5270 million metric tons	17 tonnes/year	19%	1.063 billion kW	100 (NRC)	0.0000109320442	5 (NEI)
Korea	657 million metric tons	11.8 tonnes/year	22%	94.35 million kW	24(KHNP)	0.0002462397144	4 (KHNP)

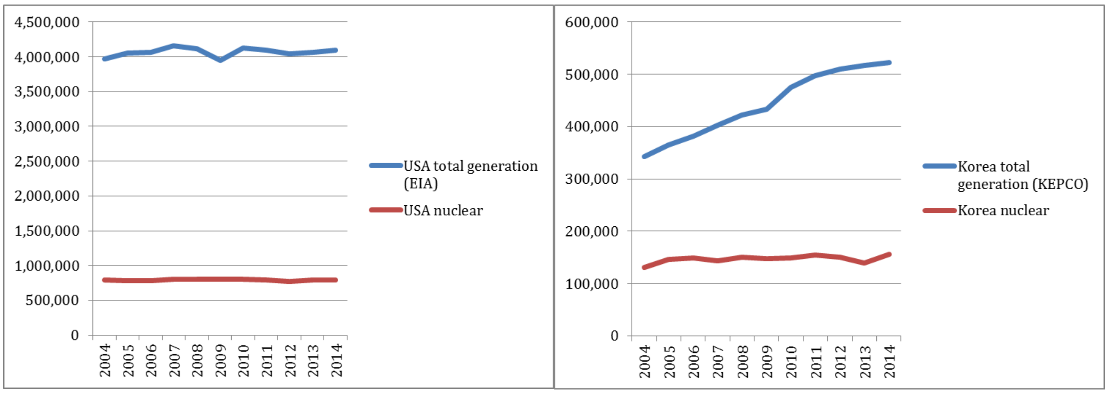

Figure 3 Nuclear and total capacity (EIA, 2015)

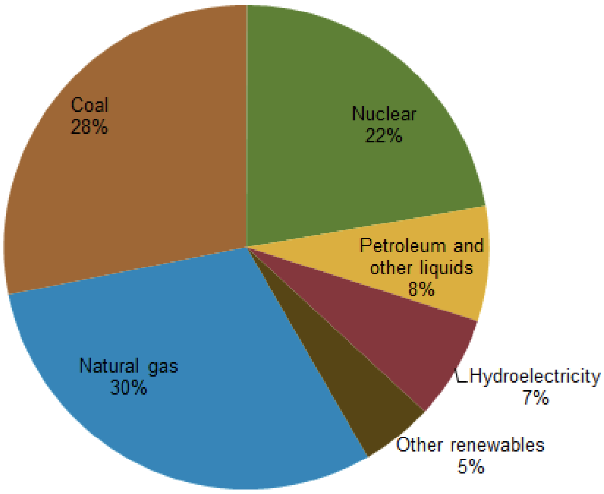

Figure 4 Korea installed electricity generating capacity by type (KEPCO, 2014)

Figure 5 Location of existing nuclear reactors and ractors in the plan in Korea (MKE, 2008)

* Source : The Fourth Basic Plan for Electric Power Supply & Demand (2008, MKE)
* MKE : Ministry of Knowledge Economy

2.4.1. Nuclear mafia in Korea

This research paper excludes cultural and social comparisons associated with nuclear power business, because Korea has a unique network in nuclear business, which cannot be compared to the United States. Most nuclear accidents in Korea happen because the nuclear reactors use inappropriate parts from unlicensed subcontractors, and this has revealed a problem of "nuclear mafias." Nuclear mafias are hidden stakeholders and authorities through nuclear networking. They are comprised of people from politics, industries, and academia. This network has been created through alumni of a few colleges, which offer nuclear related majors or programs (Lee, 2013). Vice-minister of the Ministry of Knowledge Economy addressed that "'Our' nuclear industry has certain type of cooperation. We should pass the law for extension of nuclear reactors' life expectancy. If we cannot, we should take care of our kids instead of earning money. So we must do it" (New Year address from Korea Nuclear Export Industry meeting, 2012).

Since the nuclear related work requires expert knowledge, its exclusiveness creates serious problems. Nuclear physics is an esoteric branch of science. Few experts can manage and participate in the nuclear reactors' industry, and these experts create their own networks. The public is then often denied participation in important decision-making. The meeting for permitting the Walsung 1st reactor's life extension by Korean Nuclear Safety Commission February 27th, 2015 represents this exclusive problem. The meeting was not open to public discussion, because non-experts lacked the necessary professional knowledge. Although the 4th section of article 13 of the Nuclear Safety Commission Installation and Operation Act addresses that "the meeting of commission should be open to the public," they ignored the regulation and held a closed meeting. Moreover, when some committee members denied voting because of this illegal action, they were forced to vote to fill required ballot (Ziksir, 2015).

The nuclear industry's corrupt lobbying is going around the law. Although lobbying in general is illegal in Korea, great amounts of money are lobbied in the request of mechanic parts for nuclear reactors from subcontractors to the Korea Hydro and Nuclear Power Corporation. On top of lobbying for mechanic parts, lenient examinations for nuclear plants are covered and hidden by nuclear networking (Jung, 2014). Because of this hidden power, the Korean nuclear policies are not complex and realistic enough to regulate nuclear industry, let alone evaluate the actual nuclear costs. The process of nuclear policymaking and administration is non transparent and possibly illegal. Although the nuclear mafia is the most powerful factor in the nuclear industry sector, it is endemic to Korea so this paper could not include it to the comparative study.

3. Methods

This research paper is a comparative study of nuclear policy in the U.S. and Korea. Data was principally obtained through a literature review, and by direct analysis of governmental reports and journals associated the nuclear policies in the U.S. and Korea.

This paper uses both qualitative and quantitative methods to compare the policies and nuclear costs in the two countries. The comparison of policies mainly uses the qualitative method of coding. However, most of this paper uses quantitative methods to compare the numbers associated with nuclear power generation. Nuclear Regulation Commission and Korea Nuclear and Hydro Power websites are the main sources of quantitative information on nuclear power generations. Energy Information Administration provides the overall energy consumptions, energy mix, Greenhouse gases emissions, and other background information in the both countries.

Although it is a socio-economic political study, due to cultural differences and the social structures, it excludes non-governmental powers such as nuclear mafia in Korea, and nuclear lobbying used in the U.S. to decide policies. It only compares the key policies and nuclear costs.

4. Findings A: Existing and emerging policies

This section seeks to answer the question: *What are the major policies supporting nuclear power generation, and what is the main purpose of increasing nuclear power?* Findings for this section are summarized into Table 2.

4.1. The United States

This section will focus on several policies, including the Energy Policy Act and Clean Power Plan. One is the Atomic Energy Act, which introduces background for nuclear-related laws and policies. In particular, it will examine policy objectives, functions, supporting mechanisms and incentives for nuclear industry, and impacts on the nuclear industry. The Energy Policy Act of 2005 and Clean Power Plan of 2015 are key policies that support nuclear power as one of the major energy sources in the United States. Though nuclear power was a crucial weapon during the World Wars, the policies on nuclear power focus on the perception of nuclear power as a public energy generation power.

4.1.1. Atomic Energy Act of 1954

This is a fundamental law in that it covers not only military use of nuclear, but also civilian use of nuclear materials. Section 1 declares that “the development, use, and control of atomic energy shall be directed so as to promote world peace, improve the general welfare, increase the standard of living, and strengthen free competition in private enterprise.” The Atomic Energy Act acknowledges that although atomic energy is a useful tool for economic development, it is also a potential threat to security, because it can be applied to military weapons. However, this policy changes the provisions of previous policies and allows the exchange of nuclear technologies and information via patents to foster the industry. Prior to this policy, patents were impossible to share among private industries and individual businessmen (Robinson, 2015).

The purpose of this Act is essentially to foster the nuclear industry by supporting research and development, encouraging participation, monitoring, and regulating nuclear uses. It has been amended to add sections about compensation for nuclear accidents and licensee liability. This is the fundamental policy supporting nuclear electricity in the United States; it implies that the nuclear power will maximize quality of life for citizens and improve the national economy. As this policy has established, private industry has started to enter to the nuclear sector. As Figure 3 shows, when the private industry got involved, nuclear electricity generation started to increase in 1956. However, the small increase in the late 1950s shows that this policy failed to encourage public employment, and only subsidized through taxation, which did not motivate individual business investors to get involved (Messenheimer, 1957).

4.1.2. Energy Policy Act of 2005

The main objective of the Energy Policy Act of 2005 is to combat oil shortages and climate change by creating goals, regulations, and incentives to increase energy efficiency, energy security, and clean energy use. Having enough energy supply to meet increasing demand is necessary to develop the national economy. By offering tax breaks, it encourages individuals' participation in energy efficiency programs for their existing homes, as well as the purchase of electric or eco-friendly vehicles. The Energy Policy Act also covers subsidies and tax policies for all climate change mitigation done by power generation sectors and energy policies. As the first title of this policy is Energy Efficiency, according to American Council for an Energy-Efficient Economy (ACEEE), this policy's purpose is to increase energy efficiency and encourage new energy saving technologies. ACEEE projected that this bill "would save about 2% of U.S. energy use by 2020" (2015).

Title VI includes Price-Anderson Act Amendments, general nuclear matters, next generation nuclear plant projects and nuclear security. Title VI provides financial support mechanisms for nuclear power in the Energy Policy Act by including incentives and tax credits for the domestic nuclear power industry. The government supports the nuclear industry by delaying the payment of federal risk insurance and reducing tax on decommissioning funds. This proves that funds available for decommissioning in the U.S. cannot cover the actual costs of a disaster. The government even provides nuclear power with federal loans for up to 80% of the project cost. The Price-Anderson Amendments Act of 2005 (Subtitle A) for nuclear liability protection also extends indemnification of Nuclear Regulatory Commission Licensees, Department Contractors, and Nonprofit Educational Institutions for 22 years, 19 years, and 23 years each. Moreover, it puts the nuclear power industry under the same legal standards of liability as other industrial facilities.

According to Claybrook (2005), the Energy Policy Act of 2005 gives more than $13 billion in support for nuclear power generation through subsidies on research and development, construction, operation, and decommissioning. For example, section 638 (Subtitle B), Standby Support for Certain Nuclear Plant Delays, supports new advanced nuclear facilities. It mandates that the Secretary shall pay fully covered costs of delay up to $500,000,000 per contract for 2 initial reactors. Section 645 (Subtitle C) also authorizes appropriations of up to $1,250,000,000. These funds will be provided to next generation nuclear plants for research and construction activities during fiscal years 2006 through 2015, and the sums will serve as reference for fiscal years 2016 through 2021. Moreover, Section 1306 of the Energy Policy Tax Incentives (Title XIII) declares that advanced nuclear power facility production is worth a credit of 1.8 cents/kWh during the first eight years of operation. It is available for 6000 MW of new nuclear power. This credit is treated as business credit, which can be used for carbon reduction credit. In these policies, next generation nuclear power plants mean those with designs approved by the commission after December 31, 1993. To receive tax credit, they also need to file a construction/operating license with the NRC by 31 December 2008, and begin construction before 1 January 2014, to apply for the production tax credit before 31 January 2014, and to begin operating before 1 January 2021 (Lovells, 2013).

This act encourages "plans to build as many as 25 new nuclear power plants over the next 15 to 20 years, creating a nuclear power renaissance in America," according to the Energy Policy Act Anniversary Report by the Senate (2006).

4.1.3. Clean Power Plan of 2015

This plan is an emerging energy policy to cut carbon pollution from power plants, and show that the United States is committed to leading global efforts in addressing climate change. The final rule of the Clean Power Plan asserts that its "guidelines, which rely in large part on already clearly emerging growth in clean energy innovation, development, and deployment, will lead to significant carbon dioxide emission reductions from the utility power sector that will help protect human health and the environment from the impacts of climate change." The plan hopes to reduce emissions from coal units, increase existing natural gas units, increase renewable and nuclear power energy uses, and improve energy efficiency (NERA, 2014). As this policy fundamentally aims to reduce emissions and respond to climate change, also it greatly supports renewable energy. If this plan is fully implemented, it will lead to significant reductions in carbon dioxide emissions in the electricity generation sector, decreasing carbon dioxide emissions by approximately 32% from 2005 levels by 2030. The EPA will establish guidelines for carbon dioxide emissions from existing fossil fuel-fired electric generating units (EGUs) under the authority of Clean Air Act section 111(d). This plan will work with partnerships among the federal government, state governments, and various government agencies.

After the EPA, or each state, establishes a carbon dioxide emission performance rate for fossil fuel-fired EGUs, states should flexibly develop their own plans to follow the guideline. Since the environment and situations differ by state, flexibility and latitude in how reductions are achieved is necessary to carry out effective impacts through the Clean Power Plan. Therefore, each state can create goals in three forms: a rate-based state goal measured in pounds per megawatt hour, a mass-based state goal measured in total short tons of CO2, or a mass-based goal with a new source complement measured in short tons of CO2 (EPA. 2015). States also can achieve their goals through emissions trading using emission rate credits. It is a market-based policy tool where the EPA can monitor and track the reduction of emissions in states.

The final rule of the Clean Power Plan also describes the development of new nuclear generators as the most capable and rational option to reduce emissions. Although existing nuclear generators are not covered under this rule, new nuclear reactors are qualified for issuance of emission rate credits. There are three types to incentivize new nuclear reactors based on mass-based plans: direct allocation, allowance auctions, and allowance set-asides (EPA, 2015).

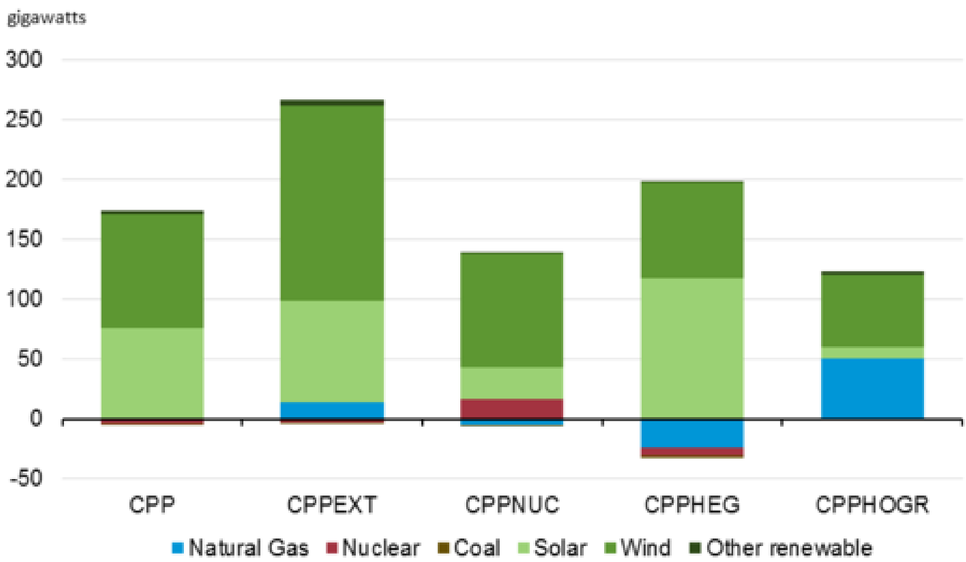

Figure 9 Change in generating capacity additions by fuel type in Clean Power Plan cases relative to baseline: cumulative, 2014-40 (EIA, 2015)

As shown in Figure 9, EIA projects five different future energy mixes, including the Clean Power Plan cases: base policy (CPP), policy extension (CPPEXT), a policy with new nuclear (CPPNUC), a Policy with High Economic Growth (CPPHEG), and a Policy with High Oil and Gas Resource (CPPHOGR). CPPNUC includes the additional new nuclear capacity addressed by the Clean Power Plan, resulting in at least twice the amount of nuclear-generating capacity than other cases in 2040 (EIA, 2015).

4.1.4. General observations on U.S. nuclear policy

On February 9, the Supreme Court addressed a hold on this policy due to a lower court ruling on its merits. However, states are already organizing their targets for compliance with the Clean Power Plan, and the industry still anticipates continuous and rising competition in clean power sectors (Kimmell, 2016). This means that the social conditions and cultures in the U.S. are accepting of a world energy transition and that the major purpose of society as a whole and industry is to reduce carbon emissions.

The main reason both the Energy Policy Act and the Clean Power Plan support nuclear power is to reduce carbon dioxide emissions. To encourage its growth and success, the government incentivizes and subsidizes the nuclear industry. The government recognizes that nuclear power is expensive, but sees its value in reducing emissions, and tries to reduce costs.

4.2. The Republic of Korea

This section will focus on policies in Korea such as the First and Second Energy Plans. The Seventh Electricity Supply and Demand Plan is a supporting policy under the Energy Plan. Thus, it outlines specific regulations and policies on electricity. Following the above analysis of U.S. policies, this section will examine policy objectives, functions, supporting mechanisms, and incentives for nuclear industry. The First and Second Energy Plans clearly determine the nuclear policy direction in Korea.

4.2.1. The First Energy Plan of 2008

The First Energy Plan is the very first energy policy aiming to achieve Low Carbon Green Development in 2008. The Energy Plan is meant to manage supply and demand for 20 years, with renewal every five years under the Energy Act. This plan includes all plans for the energy sector. It is the top policy to provide directions and rules for energy sources and other energy related plans. Korea is highly dependent on imported energy sources, so this plan aims to reduce oil imports, increase energy sovereignty, and stabilize the energy supply for economic growth. Moreover, it includes increasing renewable and nuclear power energy to reduce carbon dioxide emissions.

This plan supports nuclear power because "nuclear power satisfies both economic feasibility and environmental values." So the plan aims to expand nuclear generation up to 59% and equipment portions up to 41% of totals for electricity production by 2030.

The First Energy Plan was too focused on cheap and stable energy supply, causing the government to lower electricity prices through the addition of nuclear power plants. As the government recognized nuclear power as a cheap energy source, three more nuclear power plants started to operate after the implementation of this plan

(KHNP). Cheap electricity prices lead to more consumption and demand, causing a lack of supply. The plan increases the supply without careful management of demand. As a result, the actual energy consumption exceeds projected consumption by 3.3% (2nd Energy Plan).

4.2.2. The Second Energy Plan of 2014

Post-2020 often refers to the new era of world climate change, which forces Korea to begin reducing greenhouse gas emissions. The Energy Plan by the Ministry of Trade, Industry, and Energy presented the Korean government's plans to increase nuclear power generation out of necessity for energy security and reduced carbon emissions (Ministry of Trade, Industry, and Energy. 2014). Just like the First, the Second Energy Plan is to manage energy supply and demand for 20 years with renewal every five years under the Framework Act on Low Carbon, Green Growth, and the Energy Act. This plan includes not only the trend of energy uses but also specific governmental support for certain energy sources. Analysis of progress, and projection of national and international energy trends show how Korean energy policies should be amended for better energy efficiency. Energy security is one of the most important missions in Korea, since Korea is a peninsula blocked by North Korea, and has faced isolation in energy trading. This policy also has a plan for energy supply, energy mix, and energy efficiency with suggested directions for future policies. Moreover, for a low carbon society, it emphasizes the development of renewable energy and eco-friendly energy supply and demand. Management of energy safety is also included in this plan. Finally, it addresses Korean government support for the development of technology, resources, and human capacity. The purpose of this plan is also to improve international cooperation, because it is necessary to achieve energy security.

This plan is mainly moving towards demand management, establishing decentralized energy generation, finding a balance between environment and safety, supplying stable energy, establishing stable energy supply systems for different energy sources, and gathering information on public opinion for decision making. The third section addresses increasing investment in nuclear safety, managing old nuclear plants, and strengthening evacuation procedures. It also mentions the necessity of innovation in the nuclear industry using the application of monitoring and competition systems.

Compared to the First Energy Plan, the Second Energy Plan adjusts the facility rate down to 29% after the feedback from working groups composed of professionals, NGOs, and citizens. This plan shows Korean government support for nuclear reactors, mentioning that “there are not noticeable changes for world nuclear industry even after the Fukushima accident, so we are following the world trend”(Second Energy plan, 2014). The Second Energy Plan shows the projection of future demand and the proportion for each energy source, with the rate of nuclear power demand increasing from 32.3toe (11.7%) in 2011 to 70toe (18.5%) in 2035. This, 3.28% annual rate of increase is the second highest increase rate, following the 4.44% renewable energy rate of increase.

Since this policy was published, two additional nuclear reactors are in the process of license issuance. However, two reactors in Shin-Kori plant and two reactors in Shin-Hanul are under construction for now.

4.2.3. The Seventh Electricity Supply and Demand Plan 2015

The Seventh Electricity Supply and Demand Plan of 2015 includes electricity supply and demand quadrennial plan for 15 years from 2015 to 2019. It is included under the Energy Plan, so it mainly deals with electricity supply and demand. However, since nuclear power is highly devoted to electricity supply, this plan describes some nuclear power policies in Korea. Similar to the Energy Plan, its main goals are establishing a stable energy supply and demand; strengthening the electricity mix to reduce carbon dioxide emissions in accordance with the POST 2020 plan; and managing demand through active development of the renewable energy industry. It also hopes to stop the Kori first reactor to develop nuclear industry in the long-run, and to increase renewable energy and decentralized energy.

This plan also aims for a low carbon energy mix with nuclear power as a major energy source. Although it increases the dependence of nuclear power by 0.8% compared to Sixth Plan, it still follows the basic tracks of Sixth Plan. The Sixth Electricity Supply and Demand Plan addresses that for the nuclear facility rate to become 29% of…, a total of 43GW is needed by 2035. So the government needs an increase of 7GW to cover the goal of 36GW from nuclear power by 2024. As a result, the Seventh Electricity Supply and Demand Plan actually plans the installation of two additional nuclear reactors (total 3,000MW).

4.2.4. General observations on Korean nuclear policy

All the energy policies in Korea recognize nuclear power as a cheap energy source, and its "economic feasibility" is major reason to support it. While nuclear power increases under these policies, the growth of renewable energy is significantly slow and low. The major difference between policies of the U.S. versus Korea is the reason behind supporting nuclear power generation. The U.S. policies incentivize and subsidize the nuclear power industry to reduce carbon dioxide emissions, while Korean policies increase nuclear power generation for to energy security and stable energy demand. Moreover, the policies have different structure and complexity in the U.S. compared with Korea. While the policies in U.S. includes specific subsidies and tax credits to support nuclear, the policies in Korea just address how to increase the number of nuclear reactors.

Table 2 Overview of Key U.S. and Korea Nuclear Policies

	The United States		The Republic of Korea	
	Energy Policy Act 2005	Clean Power Plan 2015	The 1st Energy Plan 2008	The 2nd Energy Plan 2014
Main objective	To create goals, regulations, and incentives to increase energy efficiency, energy security, and clean energy use.	To reduce CO2 emissions in the electricity generation sector by approximately 32% below 2005 levels by 2030.	To achieve Low Carbon Green Development, reduce oil use, increase renewable energy and nuclear power, and stabilize the energy supply	Under the Low Carbon Green Development Act and the Energy Act, to increase electricity supply for economic development and plan demand-focused energy management for 20 years with renewal every five years
Specific objectives	Increase energy efficiency, renewable energy, hydropower and geothermal energy, climate change technology, and hydrogen; reduce oil and gas, coal, and tribal energy; improve nuclear matters and security; regulate vehicles and motor fuels, including ethanol, and electricity; provide energy tax incentives.	Reduce the emissions from coal units; increase utilization of existing natural gas combined cycle units; increase renewable and nuclear power energy uses; and increase energy efficiency (NERA)	Increase energy efficiency, security, and environmental awareness. Transition to oil independent energy society, low energy demand habits, and renewable and low carbon energy sources.	Increase energy security; plan for energy supply, energy mix, and energy efficiency; develop renewable energy and eco-friendly energy supply and demand; manage energy safety; and develop technology, human capacity, international relations, resource development, and energy welfare
How it functions	Includes tax and subsidies on the power generation either to encourage the renewable energy or to reduce the environmental pollutions.	Under the Clean Air Act, creates uniform national carbon dioxide emission performance rates for fossil fuel-fired electric generating units to reduce carbon emissions (EPA). Individual states can flexibly develop plans to meet targets. Emission rate credits may be traded amongst states or power plants. EPA provides incentives for development of clean power.	Establish the basic regulation, the Energy Act, commissions, and national goals to reduce the emissions and to increase the energy supply.	Under the Energy Act and the Low Carbon Green Development Act, set a 20 years long plan to manage the energy supply and demand efficiently, renew the plan every five years. It suggests the directions and philosophy to the sub energy policies.

Support mechanisms and incentives for nuclear industry	Delay federal risk insurance; reduce tax on decommissioning funds; federal loan up to 80% of the project cost; extension of liability protection; support for advanced nuclear technology; Approximately $13 billion subsidies and tax credits: • $500 million costs of delay • $1.25 billion costs of research and construction • Tax credit of 1.8 cents/kWh for eight years	Nuclear power is qualified for issuance of emission rate credits; incentives: • To upgrade equipment and increase a unit's capacity • For investment in new nuclear capacity • Operating license life extensions counts as credits	Set a goal for the nuclear facility portion up to 41% and nuclear generation portion up to 59% by 2030.	No changes for nuclear policy after Fukushima; the increasing growth rate is the second highest; set a goal to increase nuclear power up to 29% for total energy supply in 2020;
Impacts on nuclear industry	It encourages "plans to build as many as 25 new nuclear power plants over the next 15 to 20 years, creating a nuclear power renaissance in America (Senate)"	Under CPPNUC case, the nuclear generating capacity will increase twice more than other cases (EIA).	Three more nuclear reactors started to be operated (KHNP).	Two additional nuclear reactors are on the process of issuance (KHNP).

5. Findings B: Nuclear power costs

This section will seek to answer the question: *How have nuclear power costs been estimated and what factors have been overlooked?* Through a nuclear cost comparison of other countries that operate nuclear reactors, this section will examine whether the nuclear costs in the United States and South Korea are fairly estimated. Then, if the costs are noticeably cheaper than other countries', it means that the citizens and the public, not the operators, will pay the costs. The nuclear power costs in each country will be examined mainly by considering the costs of the compensation fund, decommissioning, and waste management.

5. Nuclear power costs

Nuclear power is economically competitive with conventional fossil fuels as a means of electricity generation because it is centralized, power intensive, and comparatively cheaper in fuel cost. Moreover, it does not emit green house gases during generation, so it reduces carbon emissions costs. Although nuclear power plants are expensive to build, they achieve economies of scale over time, and thus result in cheaper costs as power plants continue to operate. Nuclear power costs should include capital costs, plant operating costs, and external costs. Capital costs are basically investment costs, which count "site preparation, construction, manufacture, commissioning and financing a nuclear power plant (World Nuclear Association, 2015)." Plant operating costs include every other costs associated with power generation after the installation. Operation and maintenance, fuel costs, decommissioning funds, and waste management costs are the main plant operating costs. External costs usually refer to the costs to society from operation. Although other conventional power generators exclude external costs from their total costs, nuclear power internalizes these through costs such as compensation funds and waste management (World Nuclear Association, 2015). Hence, the costs associated with nuclear power are comparable to those associated with conventional fossil fuels.

5.1. Current and overall nuclear power costs

5.1.1. The United States

OECD reports in 2015 reveal that Levelized Cost of Electricity (LCOE) for nuclear plants in the U.S. (Advanced Light Water Reactor technology with 1,400 MWe net capacity) are $54.34/MWh (at 3% discount rate), $77.71/MWh (at 7%), and $101.76/MWh (at 10%). The overnight cost of nuclear power is $4,100/kWe. Table 3 shows that some costs and overnight cost are cheaper than the average for OECD countries, and the overall costs seem reasonable and moderate compared to other OECD countries. Given higher interest rates, the increases in LCOE in the US are slowing down, though the U.S. still has a high LCOE at a 3% discount rate.

EIA projects the levelized cost of advanced nuclear power in 2020 as $95.2/MWh, excluding the $18/MWh production tax credit. Levelized cost of electricity includes "capital costs, fuel costs, fixed and variable operations and maintenance costs, financing costs, and an assumed utilization rate for each plant type (EIA, 2015)." The average avoided cost of nuclear power in 2020 is $72.1/MWh, which is $23.2/MWh cheaper than the LCOE. This difference shows that the projected capacity of nuclear power will increase in the future, since levelized avoided cost of energy (LACE) is an estimate of the revenues available to that resource. So the comparison between LCOE and LACE shows how that resource is attractive to the economy.

MIT published an updated 2009 version of a 2003 study about nuclear power. The Future of Nuclear Power (2009) said, “Since 2003 construction costs for all types of large-scale engineered projects have escalated dramatically.” The updated report estimated the construction costs of nuclear power plants to be approximately 15% higher than what was uncovered in the 2003 report. The overnight cost disclosed in the 2009 version, $4,000/kW, is estimated as twice as expensive as the cost in the previous report, $2,000/kW. The MIT report further argues that that the costs for nuclear reactors in the U.S. will be higher due to construction delays and the additional regulatory requirements on the new reactors.

The estimated total costs for construction of new nuclear power plants are not settled, but severely fluctuating. The total costs including escalation and financing costs are projected to be from $5,500/kW to $8,100/kW or between $6 billion and $9 billion for each 1,100 MW plant, and are only increasing. The nuclear industry and Department of Energy introduced the overnight costs, which exclude escalating and financing costs, for new reactors as between $1,200/kW and $1,500/kW each in 2000-2002. With these overnight costs, the total costs should be around $2 to $4 billion per reactor (Schlissel, 2008). The costs have noticeably increased since 2006. Table 3 has been edited and NEA and MIT updated reports have been added. It shows the projected and actual cost of nuclear power continues to increase over time. Additionally, the report by the IER shows how new estimated costs for nuclear power have been increasing. Furthermore, given the increase in cost, nuclear power is no longer economically competitive with other energy sources (Stacy, 2015).

As can be seen from the above evidence, the nuclear power business is becoming less attractive over time as the fluctuating costs for construction increase risks in investment.

Table 3 Change of Overnight Cost

Forecast	Overnight cost (USD/kW)	Total plant cost (USD/kW)	Total Plant cost -2 units (billions USD)
DoE (2002)	$1,200~$1,500		$2~$4
MIT (2003)	$2,000		
Keyston Center (2007)	$2,950	$3,600~$4,000	
Moody's Investor Services (2007)		$5,000 $6,000	
Florida Power & Light (2007)	$3,108~$4,540	$5,492~$8,081	$12.1~$17.8
Progress Energy (2008)			$14.0
Georgia Power (2008)			$6.4 for 45% of 2 plants
MIT updated (2009)	$4,000		
NEA (2015)	$4,100 (the U.S.) $4,702 (OECD mean)		

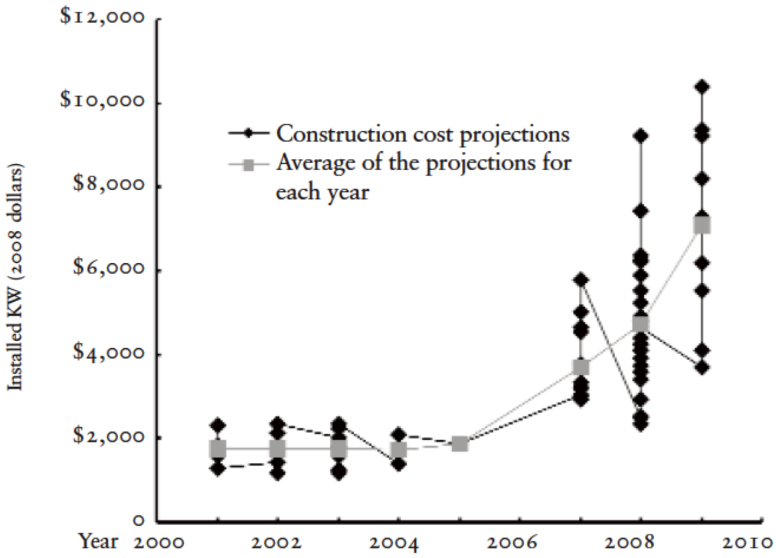

Figure 6 Capital costs projections for new power reactors in the U.S.- high and rising (Sokolski, 2010)

5.1.2. The Republic of Korea

The Levelized Cost of Electricity for nuclear power in Korea demonstrates a pattern similar to that of the United States, but even cheaper (OECD, 2015). As shown in Table 4, Korea has the same nuclear technology, Advanced Light Water Reactor (ALWR), as the United States. Its LCOE are $28.63 at 3% interest rate, $40.42 at 7%, and $51.37 at 10%. The estimated costs for nuclear power in Korea are the cheapest among the OECD countries, at approximately half of the average costs of OECD countries. All of the costs in Korea except fuel and waste are noticeably the cheapest among OECD countries. The investment costs are considerably low (three times cheaper than most countries), and Korea even estimates zero costs for refurbishment and decommissioning.

As can be seen from the above evidence, nuclear costs in Korea are relatively low while the costs are rising in the US. The major reason for cheap costs in Korea is a remarkably low estimated overnight cost. Moreover, nuclear costs in Korea do not reflect external costs well. The following sections will introduce how regulations and laws help to underestimate nuclear costs.

Table 4 Projected Costs of Generating Electricity (NEA, IEA, 2015)

Country	United States	South Korea	OECD mean
Technology	ALWR (Advanced light water reactor)	ALWR	
Net Capacity (MWe)	1,400	1,343	
Overnight cost (USD/kWe)	4,100	2,021	4,702
Investment cost (USD/MWh) 3%	30.75	10.41	25.80
Investment cost (USD/MWh) 7%	54.86	22.20	55.43
Investment cost (USD/MWh) 10%	79.16	33.15	84.37
Refurbishment and decommissioning costs (USD/MWh) 3%	1.26	0.00	1.08
Refurbishment and decommissioning costs (USD/MWh) 7%	0.52	0.00	0.29
Refurbishment and decommissioning costs (USD/MWh) 10%	0.26	0.00	0.14
Fuel and Waste costs (USD/MWh)	11.33	8.58	10.25
O & M costs (USD/MWh)	11.00	9.65	14.56
LCOE (USD/MWh) 3%	54.34	28.63	51.70
LCOE (USD/MWh) 7%	77.71	40.42	80.53
LCOE (USD/MWh) 10%	101.76	51.37	109.32

5.2. A breakdown of nuclear costs

5.2.1. The United States

5.2.1.1. Compensation fund

As mentioned above, the Price-Anderson Act (PAA) of Energy Policy Act covers the compensation fund and public liability for the nuclear power industry. Current public liability has two tiers. In the event of an accident, operators of reactors need to pay $375 million per electricity generation unit for liability. If the compensation cost will exceed this coverage, all operators from other sites should contribute up to $117 million for each unit operated too. Therefore, the total payment capacity is around $12.6 billion (Lerner). Currently, $0.001 per kWh of electricity generated at nuclear power plants has been collected for the compensation fund. Including interest since 1983, this fund is now at $42.8 billion (NEI, 2015). Although the Stafford Act does not include nuclear power plant accidents in its definition of a major disaster, the funds collected under the Stafford Act could serve as governmental assistance in the case that nuclear disaster costs exceed coverage provided by the PAA (Lerner). This means that there will be no legal requirement for the additional coverage, but the government will still try to help the refugees from nuclear disasters. As the background section mentioned, the total costs for Fukushima disaster will come to $105 billion, and about $34 billion has already been provided in compensation as of January 2014 (Lerner). The case study of Fukushima begs the question of whether the compensation fund in the U.S. would be enough for real disasters.

5.2.1.2. Decommissioning costs

17 nuclear power plants with 28 reactors are in some phase of the decommissioning process in the United States, and 11 reactors of the 28 have completed decommissioning (NRC, 2015). This compares to 61 plants and 99 reactors currently in operation as of 2016. Of these, The NEI estimates $300 million to $500 million for decommissioning costs, including $100 million in costs for management of used fuel, and approximately $300 million for site restoration (NEI, 2015). However, in the National Audit Office’s report, Managing risk reduction at Sellafield, Amyas Morse suggests the total costs will be two or three times higher than current government estimates (Morse, 2012). For example, the decommissioning cost for the Connecticut Yankee reactor was originally estimated at $410 million, but the actual total cost in 2003 was $810 million (Form 8-K, 2003). To put this in perspective, the coal power decommission cost for Idaho Power’s share of the Boardman was only $6 million (Miller, 2013).

Two kinds of subsidies may occur in the process of decommissioning. The first is if operators go bankrupt or abandon the reactors without paying decommissioning costs. For example, Tennessee Valley Authority had financial difficulties trying to cover the decommissioning costs, so the government provided low rate funds and other subsidies. The second is that governments give incentives to the operators "by taxing nuclear decommissioning trust funds at a lower rate than other business operations" (UCS, 2011).

5.2.1.3. Waste management costs

There are about 45,000 tons of spent fuel temporarily stored in the United States because no permanent site has been selected. Under Section 631, the Energy Policy Act only covers management of low-level wastes: Safe Disposal of Greater-than-class C Radioactive waste. The Nuclear Waste Policy Act of 1982 stipulates that the Federal government should have sites selected for the permanent disposal of high-level radioactive waste and spent fuel, and that plant operators should pay for the total cost of permanent disposal.

To store radioactive materials safely, the storage or disposal sites should be located deep under ground for thousands or millions of years. "Amendments to the Act have focused the Federal government's efforts, through the Department of Energy, regarding a possible site at Yucca Mountain, Nevada (NRC web)." Yucca Mountain in Nevada has been nominated for the site. The Energy Department estimated that nuclear waste management would cost more than $96.2 billion, without considering future inflation or new reactors. The Yucca Mountain project alone might cost $38.7 billion

(Hebert, 2008). However, the total nuclear waste fund has accumulated only about $21 billion (NEI, 2014).

Nonetheless, the most important point of consideration is that the Yucca Mountain project has failed and come to a halt. This means that the U.S. currently does not have a site for permanent disposal of nuclear waste while more and more reactors are in the process of decommissioning. The commercial high-level waste must then stay in temporary storage, which is usually at nuclear power plants (NRC, 2002).

A case study about waste cost analysis for the West Valley nuclear waste site suggests the real costs of cleaning up nuclear waste. It introduces two options for cleanup alternatives: waste excavation or buried waste. This cost evaluation process includes social costs, closure risks, and post-closure and geological risks. According to this study, the excavation method, estimated to cost $9.9 billion, is cheaper than the buried waste method, which would amount to $13-$27 billion.

As can be seen from the above evidence, the regulations and plans on compensation funds, decommissioning costs, and wastes management costs in the United States are well organized, as demonstrated in several case studies. Despite this, the accumulated funds are not enough to cover the actual costs, which are more expensive than expected. Most importantly, waste management faces problems of site selection and lack of funds for the construction of permanent disposal facilities.

5.2.2. The Republic of Korea

5.2.2.1. Compensation fund

Green Korea (2014), an environmental NGO in Korea, has protested Korean nuclear power generation for several reasons including public health risks, corruption in the industry, and hidden costs. It claims that the compensation fund in Korea for nuclear accidents is substantially insufficient considering the actual costs of the Chernobyl and Fukushima accidents. The current Nuclear Compensation Law 2014 (Presidential 25845th Law) covers only a \$433 million compensation fund by owners and \$43 million (based on exchange rate on Nov. 24th, 2015) for each reactor. The Environmental Dispute Conciliation Law (11267th Law) does not cover compensation for disasters related to radioactivity. Green Korea indicates that this fund equals only one eighth of the fund in the U.S. and one thirty-fifth of the Japanese fund. If the compensation cost is over \$433 million, the rest of the costs will be paid by taxes, and not by the power provider Korea Hydro and Nuclear Power Corporation (KHNP). In addition, the levelized cost does not include an acceptable coverage cost for compensation (Green Korea, 2014).

Unlike the U.S., Korea has only one tier for the compensation fund. The regulations and laws on nuclear compensation do not provide realistic coverage for actual disasters. Moreover, the nuclear LCOE in Korea does not include the compensation fund. Despite significant differences, it is important to note that the coverage of compensation funds in both the U. S. and Korea do not satisfy the actual costs.

5.2.2.2. Decommissioning costs

Green Korea also skeptically points out that the KHNP determines its own decommissioning costs (2014). The KHNP estimated $284 million per reactor and then later amended decommissioning costs to $527 million. This, however, is still far too low compared to the $861 million estimated by the International Energy Agency, and the $892 million estimated by the European Court of Auditors. The Kori 1st reactor is the first reactor scheduled to stop running in Korea. It will start the process of decommissioning in 2017. 41% of the cost associated with the decommissioning of the reactor is for management of waste from this process (KHNP blog, 2015). Although Korea has only 17 of 38 core technologies for decommissioning, the estimate for decommissioning cost in Korea is one of the cheapest among countries with nuclear power technologies (Kwon, 2015). The Nuclear Safety Law, the Presidential 26426th law, attempts to encourage extension of life span rather than decommissioning. The 20th and 23rd articles describe the process and application of extending life span and licensing. These articles allow the licensee to suggest an extension of license and let the Nuclear Safety and Security Commission examine the application.

Current law has a lack of management of decommissioning, since unlike the U.S., Korea has no experience in decommissioning nuclear reactors (Ecoview, 2014).. This means that Korea lacks case studies related to decommissioning, and underestimates the actual costs. So, while the estimated decommissioning cost in Korea is the cheapest among other OECD countries, the actual cost may not be.

5.2.2.3. Waste management costs

While the Nuclear Safety Law (Presidential 26426th Law) covers the process of licensing in the spent fuel waste industry, it only deals with the responsibilities of operators. The Radioactive Waste Management Law (Presidential 24994th Law) includes a specific process for site selection, soliciting public opinions, and managing a waste fund. The Host Regions of Low and Middle-level Waste Storage Subsidy Law (Presidential 24442th Law) states that the government will subsidize the regions within a 5 km radius of nuclear plants for storage costs up to $260 million.

The management of radioactive waste is the most expensive part of total nuclear power costs because of their extremely long half-lives. High-levels of radioactive waste need to be safely stored for a millions of years, and this is costly. In 2003, the KHNP estimated the waste management cost to be $20 billion; however, it could cost $63 billion based on Japanese Nuclear Safety Commission calculations for Japanese waste in 2012 (Green Korea, 2014). The KHNP increased the estimate for waste management costs through 2024 to $45 billion in 2012. However, the accumulated waste fund was only $2 billion in 2014 (Kim, 2015).

The low and middle-level radioactive waste storage in Kyeong-ju just finished its first step of installation in 2015. It has been 29 years since the site was selected. This first step for storage costs $577 million, and the second step will cost $224 million. This 4 km long storage abuts onto a ground-water artery, so there is great possibility of contaminating the ground water (Chosun, 2015). The site for spent fuel waste and high-level waste disposal has not been discussed yet. Provided that the temporary storage facilities in nuclear power plants are reaching capacity in 2019, a site for the disposal of high-level waste should be determined, and construction should commence in the next few years. However, the 20-year conflict for the site selection of Kyeong-ju storage implies how difficult the site selection for high-level disposal will be. Although the 2nd Energy Plan mentions limits to low-level waste disposal/treatment, high-level was not even mentioned. With regards to spent fuel, the plan deals only with the necessary accommodation of public opinions, but not technologies and costs.

Similar to the U.S., Korea has not selected the sites for permanent disposal for used nuclear fuel. However, site selection will be substantially harder than in the U.S., because Korea has smaller land territory and higher density of nuclear reactors. This means that Korea has fewer choices for site selection.

As can be seen from the above evidence, Korea has looser regulations and laws about compensation funds, decommissioning costs, and waste management costs than the U.S. These regulations cause not only the cheapest estimated nuclear costs, but also the highest risks for the disasters. The costs of compensation decommission, and waste management in Korea seems to be overlooked and insufficient in many ways compared with the U.S.

6. Discussion and conclusion

The first part of the findings section (Findings A) shows how various key policies in each country support nuclear power over time. In the U.S., the Atomic Energy Act of 1946 creates the private and individual nuclear power business, as the government allows a civilian use of the nuclear power. The amendment of 1954 allows sharing and exchanging information to foster the industry. Then, the Energy Policy Act of 2005 passionately promotes nuclear power as a reaction to climate change in the name of new technology for the development of energy efficiency. This policy provides a great amount of incentives and tax credits for the nuclear industry. Through this process, the decommissioning fund decreases. The Clean Power Plan of 2015 proves the greatest change in U.S.'s position. In the world climate change conferences, and domestically, it reflects that the government will increase the proportion of nuclear generation as a carbon-free power source.

While the U.S. supports and highlights nuclear power as clean energy source, Korea supports nuclear power mainly because of its cheap cost. The main objectives of the First Energy Plan of 2008 are reducing foreign energy sources and increasing energy supply in which nuclear power is the solution because it is cheap and powerful. Then, the Second Energy Plan shows the changed weight of energy policy; Climate change becomes the first concern, but nuclear power is still the solution to reduce greenhouse gases emissions.

The major differences between the U.S. and Korea are their respective purposes for nuclear power generation and the structures of nuclear power operations. First, the nuclear industry in the U.S. is an open market, only regulated or subsidized by the government. The state-owned company, in contrast, operates nuclear power in Korea, so that the government can determine cheap generating costs to support the nuclear power. The major policies show the use of different terms in supporting nuclear power. The policies in the U.S. include tax credits and subsidies to the industry while Korean policies just address plans to increase the number of nuclear reactors. Second, the highlighted reason for supporting nuclear power in the U.S. is a reduction of carbon dioxide emissions, and Korea supports nuclear power because it is the cheapest energy. However, policies in both countries emphasize the impact of climate change and energy security. As a result, both renewable energy and nuclear power have increased under the policies in the U.S. However, only nuclear power generation has rapidly grown in Korea while the rate of growth of renewable energy is the lowest compared with other OECD countries.

The second part of the findings section (Findings B) shows the specific comparisons of nuclear costs in the U.S. and Korea. Although the nuclear costs in the U.S. seem more acceptable than those in Korea, in both countries the reflection of costs in electricity prices are still not compatible enough with actual costs when disasters and decommissioning happen. The construction overnight costs for both countries are lower than the average cost for OECD countries, and the Korean nuclear costs are even twice as cheap as the average cost.

The experiences of decommissioning in the U.S. give feedback on costs and policies so that the government recognizes the gap between projected and actual costs. The U.S. government responds to the increasing costs with more subsidies to reduce the Greenhouse gas emissions. In contrast, Korea does not have any experience with decommissioning and compensation. This lack of experience causes the costs to be underestimated. Moreover, the Korean government overlooks population density and small size of territory. Although higher population density will need a much larger compensation fund, and lack of sites for nuclear waste disposal will increase the opportunity costs, estimated Korean nuclear costs remain the cheapest among OECD countries.

As a result, both countries need more accurate representation of projected nuclear costs. The proper cost determination for the nuclear industry in the U.S. will lead to better policy making, and allow for a process to reduce the greenhouse gas emissions and increase reliability. However, the right cost determination for generating nuclear power in Korea might lead to reduction of nuclear power use once it is realized and communicated transparently to the public that nuclear power is not economically competitive with alternative energy sources.

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