International Interconnection in East Asia

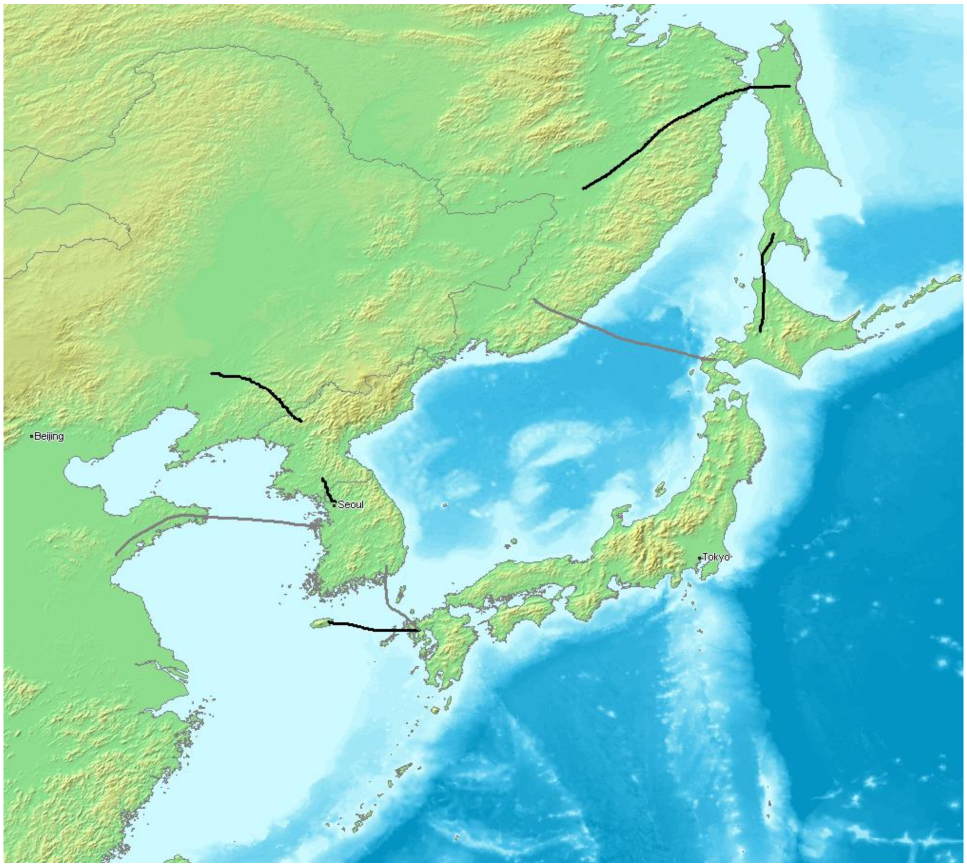

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Table of Contents

Table of Figures

Table of Tables

List of Abbreviations

Organizations

CSP – China State Power

EBRD – European Bank for Reconstruction and Development

EIA – Energy Information Administration

ENSTO-E – European Network of Transmission System Operators for Electricity

JEPX – Japan Electric Power Exchange

KPX – Korea Power Exchange

NASA – National Aeronautics and Space Administration

NEB – National Energy Board

NEI – Nuclear Energy Institute

TSO – Transmission System Operator

UES – Unified Energy Systems

WNA – World Nuclear Association

Power Terminology

Power is the rate at which energy is generated or consumed.

AC – Alternating Current

DC – Direct Current

GWh – Gigawatt hour. 1 Gigawatt is 1000 Megawatts

HVDC – High Voltage Direct Current

Hz – Hertz.

km – kilometer. 1 kilometer is 1000 meters

kWh – kilowatt hour. 1 kilowatt is 1000 watts

MWh – Megawatt hour. 1 Megawatt is 1000 kilowatts

TWh – Terawatt hour. 1 Terawatt is 1000 Gigawatts

Abstract

China, Japan, North Korea, South Korea, and Russia are prime candidates for an international interconnection. Some of these countries face certain problems with their power grids: Japan, North Korea, and South Korea are island grids and also have issues with land use; China cannot keep up with the increasing power demands from its rapid economic growth, and Japan is shifting its generation focus away from nuclear and towards renewables. Being interconnected would solve all of these issues in addition to providing numerous benefits to each country.

The purpose of this paper is to show the costs and benefits of an international interconnection among five countries in East Asia: China, Japan, North Korea, South Korea, and Russia. By using high voltage direct current (HVDC) and alternating current (AC) transmission lines, connections will be made across borders over land and underwater. There are many benefits to an international interconnection, including technical, economic, social, and environmental benefits. Technical benefits include smoother load curves – which leads to better efficiency – right-of-way issues, and a diverse supply of energy.

Economic benefits include increased use of low cost fuels, encouragement of economies of scale, decreased fuel imports, and an indirect benefit to economic growth. Social benefits include an increased quality of life in, but not limited to, education, business, healthcare, and agriculture. Lastly, environmental benefits include increased air and water quality and decreased water and waste use. Successful interconnections between the United States and Canada, along with the connected European grid, shows that an international interconnection is possible in either a small or continental scale. Despite the technical, economic, and environmental costs of the interconnection, the benefits of the interconnection outweigh the costs.

1. Introduction

This paper is a costs and benefits analysis on an international interconnection among five countries in East Asia: China, Japan, North Korea, South Korea, and Russia. This area is a prime candidate for an interconnection because of key issues that plague the area, including, but not limited to, energy security and fuel dependency. The interconnection would not only solve most of these issues, but also provides numerous benefits as well. With successful international interconnections occurring more frequently throughout the world, notably in North America and in Europe, an interconnection in East Asia is not only possible, but also practical.

Currently, there are several issues with the five countries. First of all, Japan, North Korea, and South Korea are island grids; they are not connected to any other power grid and are dependent on their own abilities to generate electricity.[1] Additionally, because of the size of their countries, Japan and South Korea have trouble finding space for their generation facilities.[2] Russia and China are connected, with Russia exporting 2,630 million kWh of electricity to China in 2013.[3] However, despite this import, China is still failing to meet the rapidly rising demand of electricity due to lack of transmission efficiency and a shortage of coal.[4] Lastly, Japan has been trying to move away from nuclear and more towards renewable energies, though doing so may cause severe debt problems.[5]

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[1] Wang, 2000
[2] Yun and Zhang, 2005
[3] Inter RAO, 2013
[4] Bai and Aizhu, 2011
[5] Tabuchi, 2012

2. Proposal

2.1 Benefits of HVDC

For the international interconnection, the use of both high voltage direct current (HVDC) transmission lines and alternating current transmission lines between each of the countries is included this proposal. The use of HVDC lines is preferred over the use of alternating current (AC) transmission lines for three main reasons: long distances, asynchronous frequencies, and undersea cables. In certain areas, the distance between transmission lines is extensive. While it is possible to connect two power systems using AC lines, the cost to connect them will be greater than using HVDC. The following figure shows the cost of AC vs. the cost of HVDC.

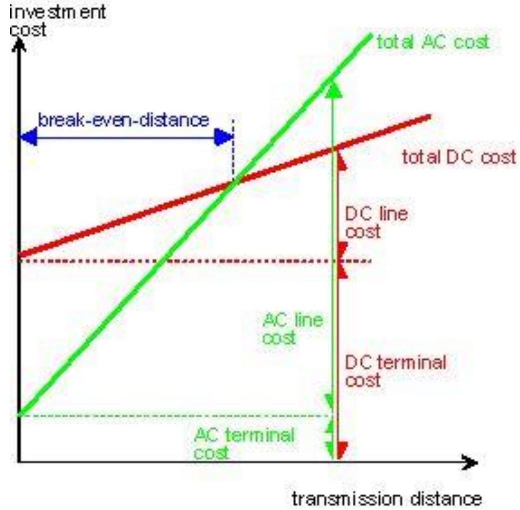

Figure 1: Graph of AC vs. DC Costs
Source: ABB

As seen in this figure, as the distance between two stations increases, the total cost for both AC and DC lines increases as well. However, DC costs increase at a much slower rate than AC does and therefore, once the line distance hits a certain point, it will be more cost effective to use DC transmission over AC transmission.

Another benefit DC transmission lines have over AC transmission is that the lines must traverse bodies of water. Bodies of water separate the countries from each other, specifically, Japan to the others. AC transmission systems underwater reduce the load capability due to high capacitance, which leads to power losses.[6] However, DC transmission systems do not have this problem because the DC lines do not have to deal with frequencies. Additionally, the distance

[6] Ragheb, 2012

between Japan and the other countries is at least 200 km. Again, while it is possible to connect Japan with the other four countries with AC lines, the cost to do so will be higher than using HVDC.

Lastly, the deciding factor as to why HVDC should be used over AC is asynchronous frequencies. The frequencies among the five countries are either 50Hz or 60Hz.[7] Unfortunately, AC currently does not have the technology to connect asynchronous systems and as a result, HVDC will be the best choice to connect countries with differing frequencies.

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[7] McGregor, 2013

2.2 Interconnection Location

For the interconnection, it is important to utilize a country's power grid to save costs. The following figure displays all of the potential connections among the countries.

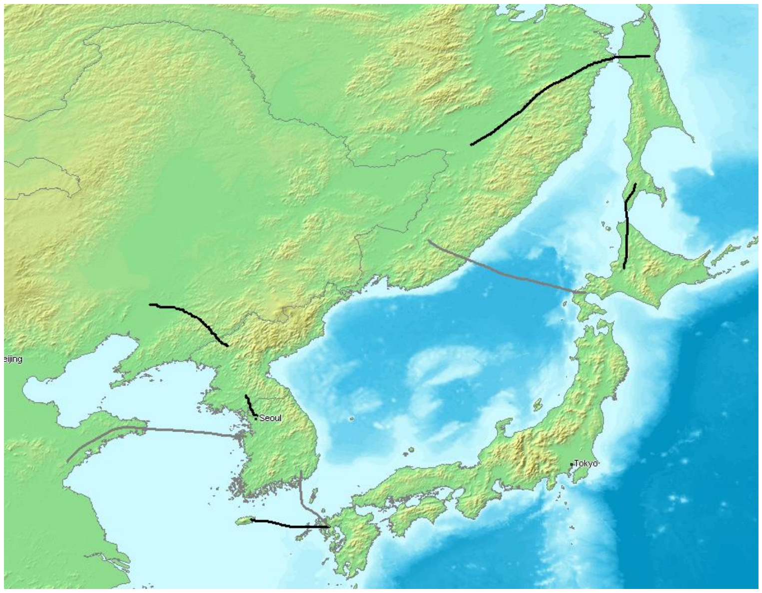

Figure 2: International Interconnection Proposal

The black lines are potential and preferred interconnection while the grey lines are alternatives. For the interconnection between Japan and Russia, there are two (2) potential locations to connect the two countries. Figure 3 shows these locations.

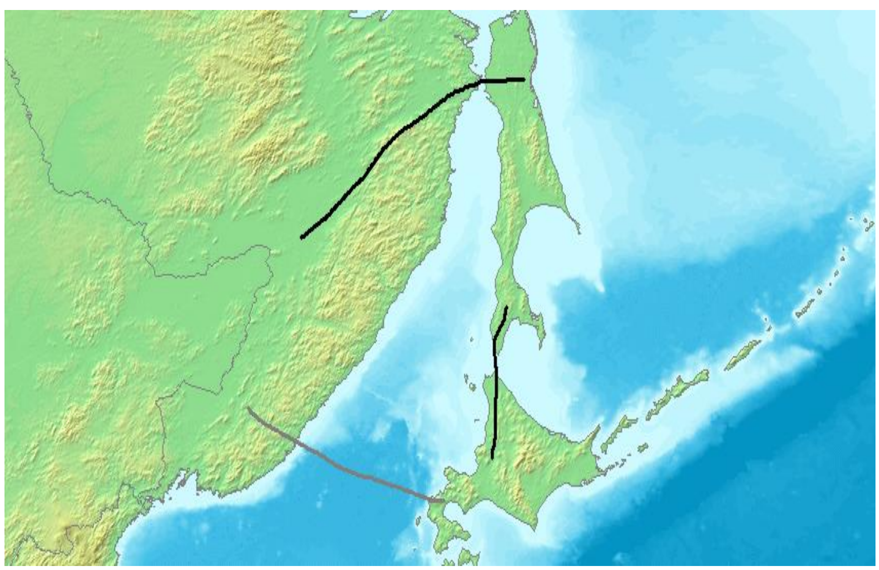

Figure 3: Interconnection between Japan and Russia

One potential path is to go from Hokkaido to Primorsky Krai. The costs will be two (2) converter stations and an extremely long HVDC line going undersea and then back up on land, which will be around 500 – 600 km. Another option would be from Hokkaido to Sakhalinskaya. However, four (4) converter stations will be needed, two stations between Hokkaido to Sakhalinskaya and two stations between Sakhalinskaya and the rest of Russia. This is because Sakhalinskaya is an island grid and does not connect to the main grid in Russia. Alternatively, an AC transmission system over the water might suffice, depending on weather conditions.

For the interconnection between Japan and South Korea, Figure 4 shows two (2) potential locations to connect the countries together.

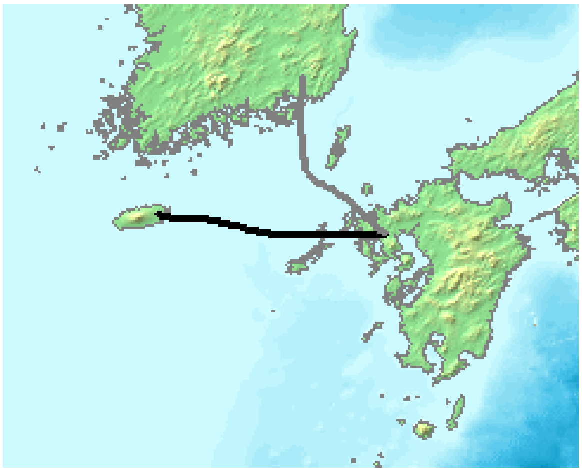

Figure 4: Interconnection between Japan and South Korea

There are two (2) potential ways to connect Japan and South Korea. The first converter station would be located at or around Fukuoka. The second station would either be the current station on Jeju or a new one in Busan. Although there might be some costs averted when connecting to Jeju by utilizing an existing converter station, the distance from Fukuoka to Jeju is about 300 –350 km, while the distance between Fukuoka to Busan is only 200 – 220 km.

The differing potential locations among China, North Korea, and South Korea depend on the political situation. Figure 5 shows an example of what these locations might be.

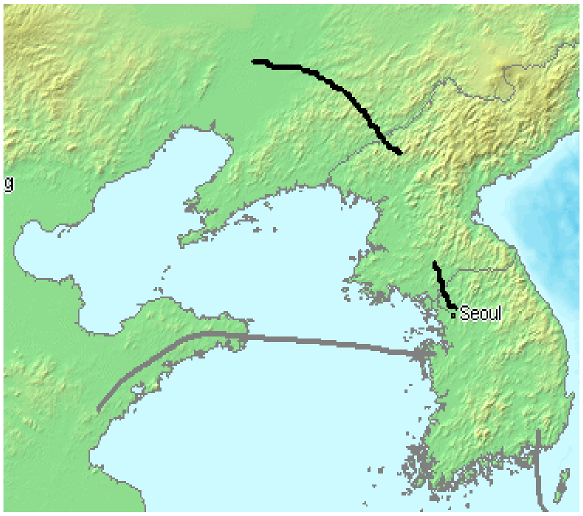

Figure 5: Interconnection among China, North Korea, and South Korea

There are two (2) possibilities, depending on how cooperative North Korea wants to be. If North Korea is cooperative, an HVDC link from South Korea to North Korea and then from North Korea to Liaoning/Jilin would be ideal. If North Korea is not cooperative, then a longer undersea line from Incheon to Shandong would have to suffice, though it is not ideal due to length (375 –400 km) and additional construction of transmission lines across land.

3. Benefits

There are a number of potential benefits and impacts related to the international interconnection. These range from technical, economic/financial, social, and lastly, environmental.

3.1 Technical

There are many advantages in the interconnection from a technical standpoint. One major benefit from the interconnection comes from the smoothing of peak loads. The following graph shows the peak loads of four of the five countries in the affected area (data from North Korea was unavailable at the time of writing, though the peak load for North Korea is to be assumed during the winter nighttime).

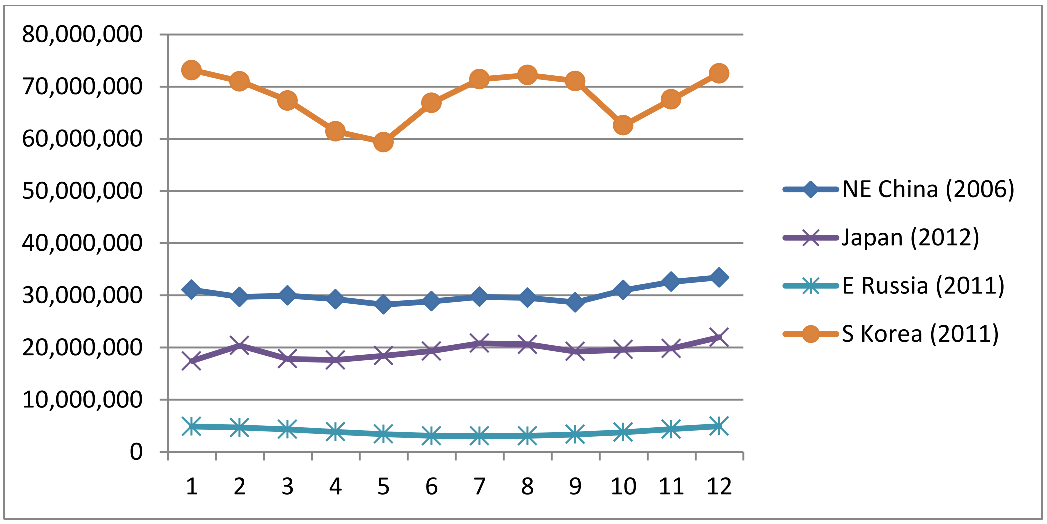

Figure 6: Peak loads for China, Japan, South Korea, and Russia in MWh
Source: Author, with data from JEPX, KPX, EBRD, and CSP, 2013

This figure shows that South Korea has the most energy usage, followed by Northeast China, Japan, and East Russia at the end. Additionally, South Korea has the most varying peak usage, whereas the other three countries have a relatively stable peak load usage. Because of this, a country could now change its generation behavior to cover a smoother load while having the peak loads covered by importing electricity from other countries. For example, the following figure shows how East Russia could theoretically change its load generation.

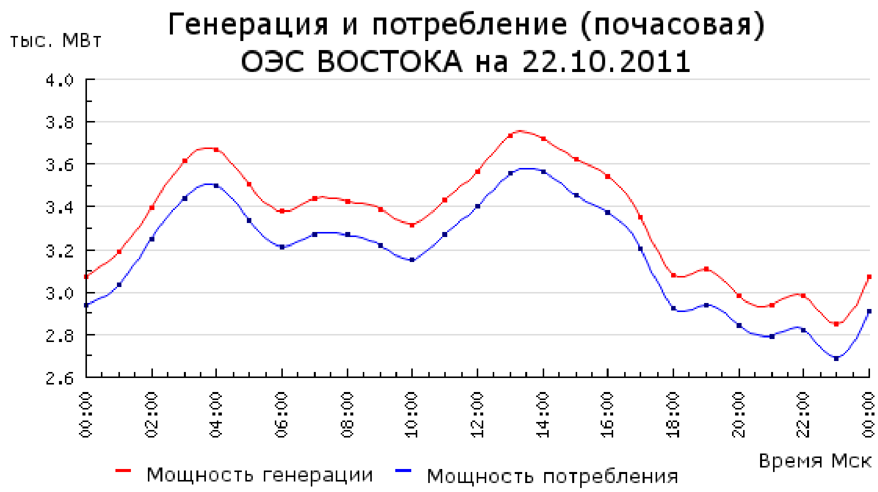

Figure 7: Load Graph During 22 Oct 2011
Source: UES

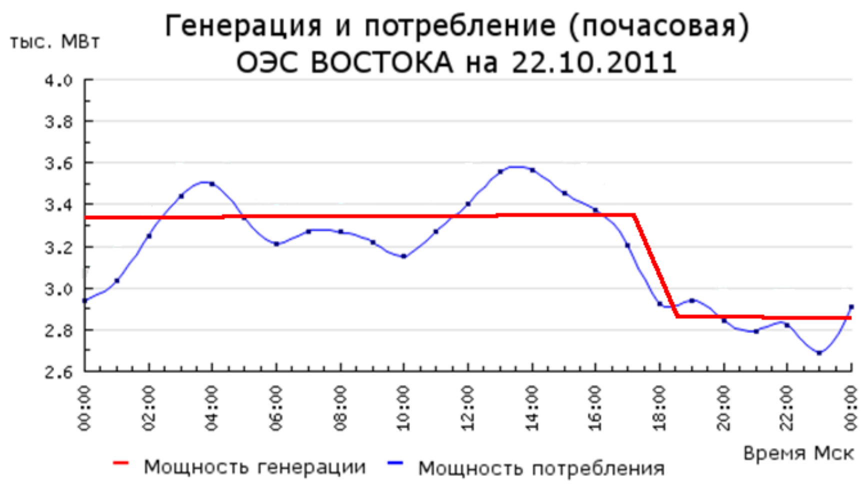

Figure 8: Changed Ideal Load Graph
Source: UES

As shown in Figure 8, the generation curve could theoretically be flattened, with peak loads being covered by other generation facilities in different countries. With the smoothing of the load curves, this would lead to a more efficient power system by being able to utilize more of a power plant. Currently, power plants are made to handle peak loads and only run at a fraction of its nominal/efficient generation. By letting a power plant run at its most efficient generation state, any extra electricity generated can be sold to other countries in need of electricity due to peak demand.

An international interconnection would solve South Korea's and Japan's issues on the size of their countries. As it stands, Japan and South Korea both have a difficult time finding sites for the generation facilities due to the lack of land. The following figures show the land usage of both countries.

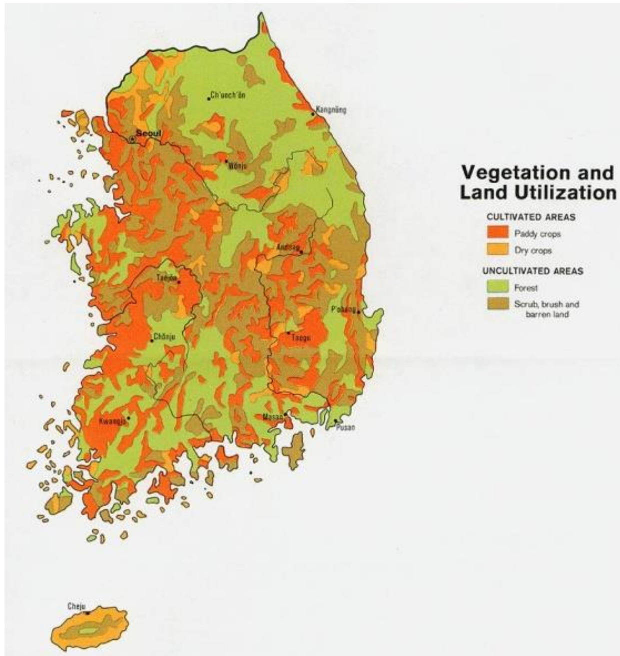

Figure 9: Land Usage for South Korea
Source: FETEC Geographic Information System

Figure 10: Korea Topography
Source: maps.com

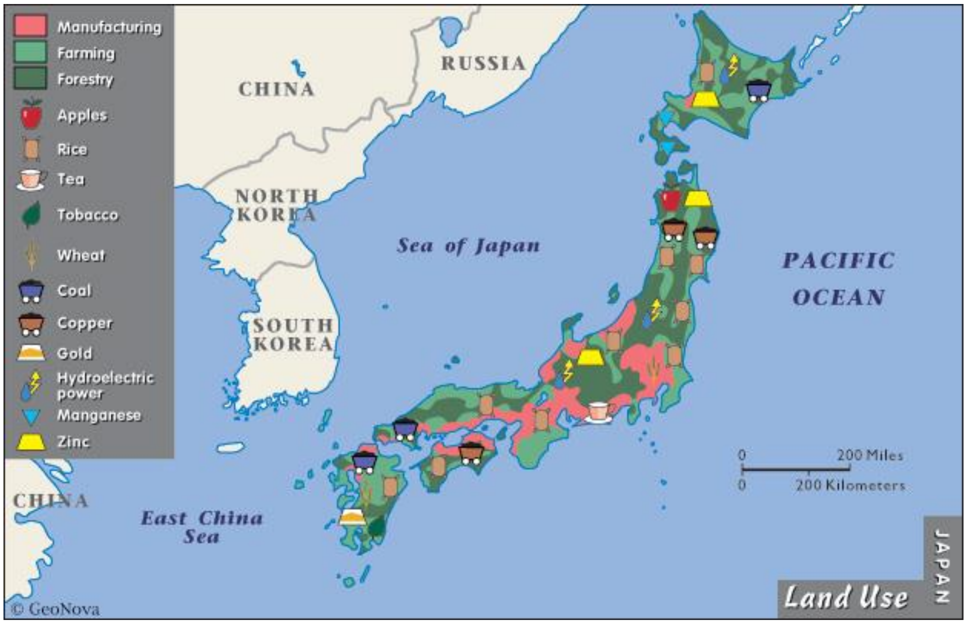

Figure 11: Land Usage for Japan
Source: howstuffworks.com

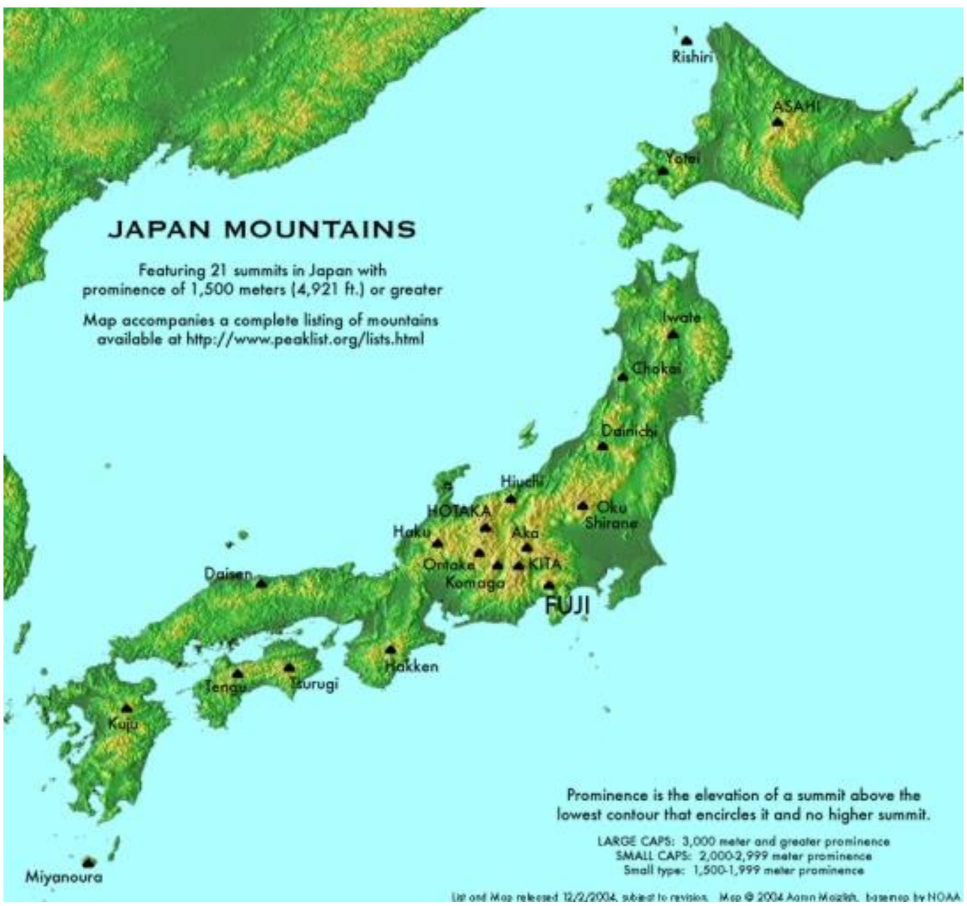

Figure 12: Japan Topography
Source: peaklist.org

As shown in the maps above, a majority of the land is used for farmland or is a forest area. Additionally, especially so in South Korea, mountains cover a good portion of the country. With the implementation of the interconnection, the need to find sites for power plants disappear because needed electricity during peak loads can be imported from other countries.

Interconnectivity provides additional benefits as well. Being interconnected allows electricity to not go to waste; a generating facility may plan to sell additional electricity and thus may end up not being able to meet the demand due to the facility's generating capacity. This allows countries to build generation facilities with much bigger capacity, which benefits smaller countries, such as Japan and South Korea, where space is limited. Countries would not have to worry about wasted electricity from these massive capacity generation facilities because of the interconnection.

Lastly, an international interconnection would provide a diverse supply of energy to all of the countries interconnected. In the five countries listed in this proposal, each country uses thermal energy for the majority of its power generation, which includes oil, natural gas, and coal as fuel. However, each country utilizes different alternative fuels to generate electricity; for example, Japan and South Korea use nuclear and renewables while China and Russia both use hydroelectricity.[8] Because each country's environmental conditions differ greatly from its neighbors, countries may be able to support one another during a time of crisis. For example, a severe drought would cripple North Korea's and China's hydroelectric plants, but with the help of Russia's hydroelectric plants and Japan's nuclear power plants, North Korea and China would not suffer as much. Having a diverse mix of fuel source would greatly enhance the reliability of the interconnected power system.

3.2 Economic

There are numerous economic benefits to an international interconnection. As mentioned in the technical portion of this proposal, the interconnection has the potential to smooth out peak load curves, thus improving load factor. By smoothing out peak load curves, this allows countries to focus their generation units more on supplying the most efficient power as possible. This is vastly different from the current model of building power plants to compensate for peak loads and thus operating them at far lower than optimal ratings. By focusing more on efficiency

[8] International Energy Agency 2013

rather than peak demand, this allows countries to not only maximize the power generated, but it leads to numerous other benefits.

One of benefits of maximizing efficiency leads to maximizing fuel efficiency and consumption, which will lead to avoided fuel and operating costs. The following is a table of fuel and operation costs.

Plant type	Capacity factor (%)	U.S. average levelized costs (2011 $/megawatthour) for plants entering service in 2018				
		Levelized capital cost	Fixed O&M	Variable O&M (including fuel)	Transmission investment	Total system levelized cost
Dispatchable Technologies						
Conventional Coal	85	65.7	4.1	29.2	1.2	100.1
Advanced Coal	85	84.4	6.8	30.7	1.2	123.0
Advanced Coal with CCS	85	88.4	8.8	37.2	1.2	135.5
Natural Gas-fired						
Conventional Combined Cycle	87	15.8	1.7	48.4	1.2	67.1
Advanced Combined Cycle	87	17.4	2.0	45.0	1.2	65.6
Advanced CC with CCS	87	34.0	4.1	54.1	1.2	93.4
Conventional Combustion Turbine	30	44.2	2.7	80.0	3.4	130.3
Advanced Combustion Turbine	30	30.4	2.6	68.2	3.4	104.6
Advanced Nuclear	90	83.4	11.6	12.3	1.1	108.4
Geothermal	92	76.2	12.0	0.0	1.4	89.6
Biomass	83	53.2	14.3	42.3	1.2	111.0
Non-Dispatchable Technologies						
Wind	34	70.3	13.1	0.0	3.2	86.6
Wind - Offshore	37	193.4	22.4	0.0	5.7	221.5
Solar PV[1]	25	130.4	9.9	0.0	4.0	144.3
Solar Thermal	20	214.2	41.4	0.0	5.9	261.5
Hydro[2]	52	78.1	4.1	6.1	2.0	90.3

Table 1: Fuel and Operation Costs
Source: EIA

As shown in the table, natural gas has the highest fuel and operation costs, ranging from $45.0/MWh to $80.0/MWh. Additionally, coal ranges from $29.20/MWh to $37.20/MWh. These costs are great when compared to renewable resources, such as solar, wind, and geothermal - which have $0/MWh fuel and operating cost - and hydro, which has a $6.10/MWh fuel and operating cost. Even nuclear, which has a fuel and operating cost of $12.30/MWh, has a better fuel and operation cost than coal and natural gas. Therefore, in order to be more cost effective, countries should shift away from natural gas and coal and utilize renewable energy and nuclear power more. However, this economic benefit only occurs on existing generation facilities. If additional generation facilities were to be built, the total system levelized cost would be taken into consideration, making an advanced combined cycle and conventional combined cycle natural gas-fired generation facility more favorable and cost-effective over the others.

As mentioned in the technical portion of this proposal, the interconnection would greatly smaller countries such as Japan and South Korea by discouraging generation siting and encouraging the use of economies of scale. This also helps these countries economically as well, though in an indirect fashion. Because of the high costs of building generation facilities, smaller countries would save money because of what the interconnection would do; it would discourage generation siting. Additionally, by building bigger, countries can save money because of the fact that building bigger generally leads to bulk prices and thus save costs on fuel. By discouraging generation siting and encouraging economies of scale, the interconnection helps smaller countries with land use issues.

Lastly, the interconnection would greatly benefit countries that have to import fuel in order to run generating facilities. This affects smaller countries, such as Japan and South Korea, countries that do not have a lot of natural resources. In 2012, Japan imported 4,593.03 thousand barrels of petroleum per day, 4313.87 billion cubic feet of natural gas, and 192.992 million short tons of coal.[9] South Korea imported 2,207.28 thousand barrels of petroleum per day, 1,670.79 billion cubic feet of natural gas, and 138.165 million short tons of coal in 2012.[10] If the interconnection were to be completed, electricity would be imported rather than importing costly fuels.

On the national level, the interconnection will provide a more stable, more reliable power system. With this reliable system, local economies can thrive and contribute to their country. Countries that have trouble maintaining a reliable supply of electricity, such as China and North Korea, will be able to have access to a nearly 24/7 power system. This will lead to businesses being able to run without the fear of having their power cut off, which would lead to a loss of money. The benefit of having a stable power supply indirectly benefits a country's economy.

Additionally, excess electricity can be produced by a nation and thus can be sold to other nations in demand of electricity. Currently, as mentioned before, countries import fuel for their generation stations to produce electricity for themselves. With the interconnection, countries can

[9] U.S. Energy Information Administration, 2012
[10] U.S. Energy Information Administration ,2013

import electricity instead of fuel. Using this new model, countries with large amounts of fuel reserves can make a profit off of these reserves by producing electricity and selling it to countries in need of it.

3.3 Social

While four of the five countries in this proposal have a relatively reliable power system, North Korea does not. The famous picture of North Korea during the night is a testament to its unstable power system.

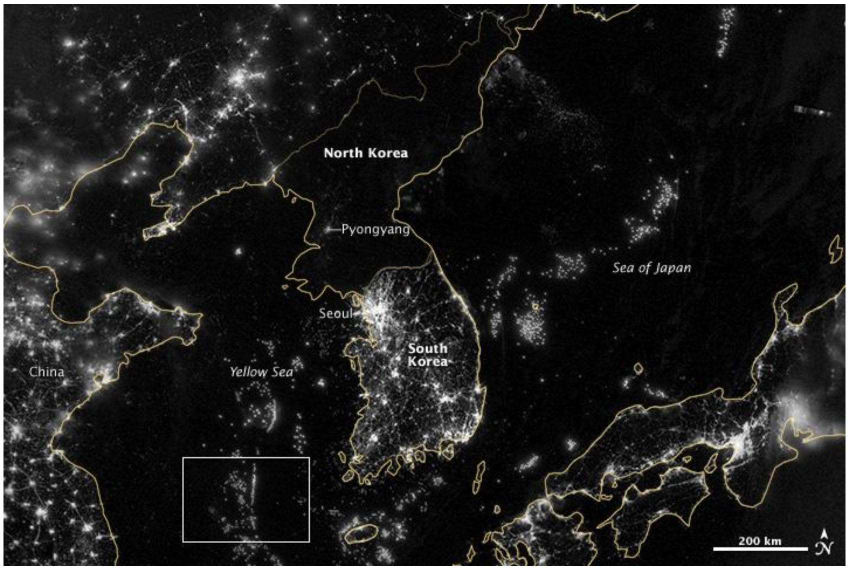

Figure 13: Korea at Night
Source: NASA, 2011

However, North Korea is not the only country that has power system reliability issues; China has been building faster than its generation capability can handle, thus leading to power shortages. An international interconnection will greatly improve the power systems of all countries, thus bringing with it many social benefits.

Having an uninterrupted power supply greatly benefits everyone. In terms of education, students will have access to light during the night and therefore will not have to resort to using candlelight. Additionally, the uninterrupted power supply will allow the use of computers and students will have opportunities to take night classes. In healthcare, hospitals will have access to refrigeration, which will extend the life of medicines that require refrigeration, and will allow doctors and surgeons to care for their patients during the night. For businesses, companies can operate without fear of having the power cut out and thus lead to more employment opportunities. Lastly, for agriculture, the use of electricity can help with water pumping and crop processing which will lead to better food quality and quantity. Having access to electricity will greatly benefit a country and would help encourage the development of a country.

3.4 Environmental

With potential environmental benefits and impacts, almost all of them come at the generation level. While the construction of the interconnection brings unavoidable impacts to the environment, almost all of these impacts are transient and, therefore, relatively short term. In terms of potential air benefits and impacts, the interconnection can help reduce (or contribute to) the amount of air pollution. This is done through the location of generation plants and the use of certain generation plants over others.

If done correctly, the interconnection can shift thermal power generation from crowded areas, such as China, Korea, and Japan, to the remote areas of the Russian Far East, thereby reducing the pollutants in the local area. Additionally, the use of certain plants can be used over others in order to reduce greenhouse gas emissions. The following figure is a graph of greenhouse gas emissions throughout the lifecycle of a generation plant.

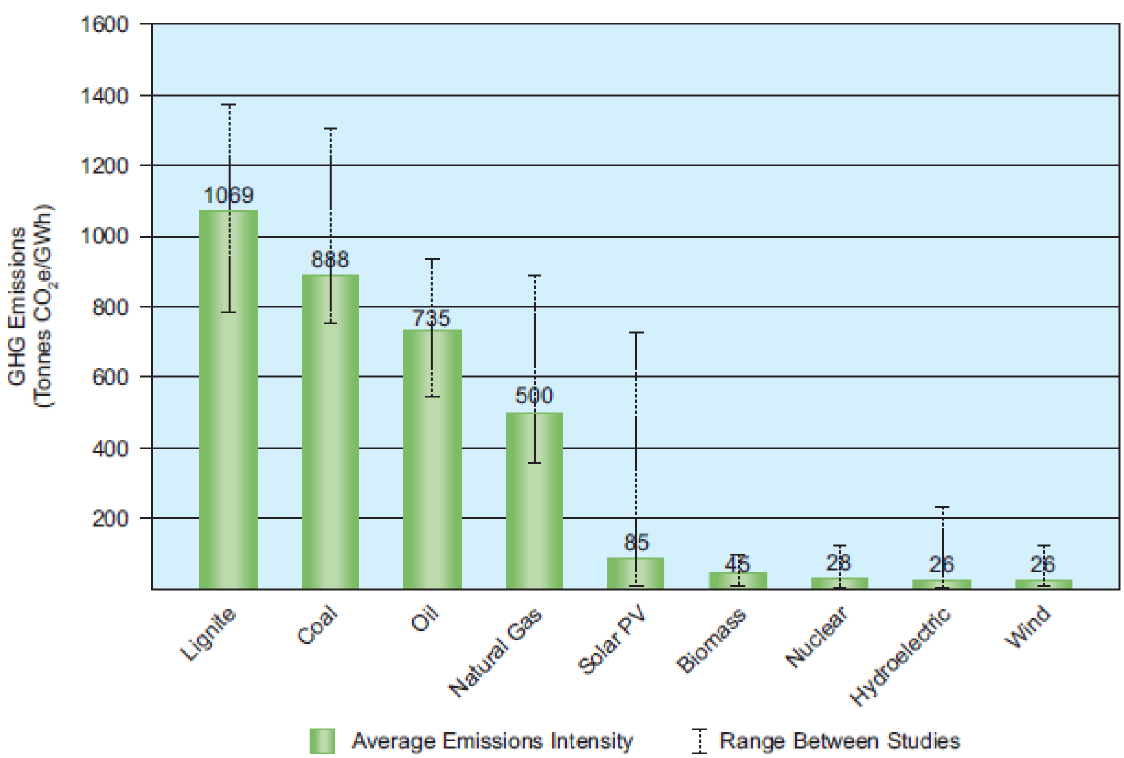

Figure 14: Lifecycle Greenhouse Gas Emissions Intensity of Electricity Generation Methods
Source: WNA

As shown in the figure, the generation types that have extremely low greenhouse gas emissions are biomass, nuclear, hydroelectric, and wind, while lignite, coal, oil and natural gas all have high greenhouse gas emissions. Therefore, if a switch is made from these high greenhouse gas emitting generators to the low greenhouse gas emitting generators, the overall greenhouse gas emissions should be lowered. This will result in a reduction to greenhouse gases and pollutants and thereby reducing the carbon footprint of a country.

Water pollution and water use is a more difficult matter to handle due to the fact that there is a greater chance at a potential impact than a benefit. Additionally, it should be noted that water pollution and usage is much more prevalent than air pollution during the construction phase of the interconnection. As with air pollution, water pollution has the potential to be reduced in the generation side. The following table shows the amount of water pollution and usage created by each fuel type.

Biomass	Plant use ranges from 500 to 900 gallons per MWh to 20,000 to 50,000 gallons per MWh. Water used for cooling returns warmer than before negatively impacting marine life. Additionally, water is needed to produce biomass fuel ranging from 40,000 to 100,000 gallons per MWh.
Coal	Plant use ranges from 500 to 600 gallons per MWh to 20,000 to 50,000 gallons per MWh. Coal mining contributes to water pollution through acid mine drainage.
Geothermal	Plant use ranges from 1,700 to 4,000 gallons per MWh
Hydroelectric	Plant uses water as a source of generating electricity. No water pollution from using the water, but dam may lead to water stagnation.
Natural Gas	Plant use ranges from 100 to 230 gallons per MWh. Fracking constitutes the majority of water use, ranging from 2 million to 10 million gallons per well.
Nuclear	Plant use ranges from 700 to 1,100 gallons per MWh to 20,000 to 60,000 gallons per MWh. Uranium mining contributes to groundwater contamination.
Solar	Solar PV ranges from 255 to 520 gallons per MWh. Concentrated solar thermal plants require about 600 to 650 gallons per MWh for cooling. Also note that solar plants are located in hot, dry regions where water is scarce.
Wind	Plant use ranges from 55 to 85 gallons per MWh.

Table 2: Water Pollution created by Each Fuel Type
Source: Author, with data from Civil Society Institute, 2013

As shown in this figure, nuclear, coal, and natural gas all are great offenders of water pollution and usage. Biomass and, to a lesser extent, solar use water; but, not to the extent the first three fuel types do. Lastly, wind has very little water pollution, with only offshore wind turbines disturbing marine life. Therefore, if water pollution was the only factor in deciding which fuel type to use, wind power, along with biomass and solar, would be preferred over all others.

In addition to water and air pollution, the construction of the interconnection and power plants generate wastes as well, both solid and hazardous. These wastes are unavoidable, regardless of the type of power plant. However, these wastes can be reduced through the interconnection. The following table shows the amount of waste generated for each fuel type.

Biomass	Produces ash, but contains extremely low levels of hazardous elements.
Coal	125,000 tons of ash and 190,000 tons of sludge
Geothermal	Does not produce substantial amounts of solid waste
Hydroelectric	Does not produce substantial amounts of solid waste
Natural Gas	Does not produce substantial amounts of solid waste
Nuclear	20 tons of spent nuclear fuel after one year
Solar	Does not produce substantial amounts of solid waste. However, production of photovoltaic wafers creates very small amounts of hazardous waste.
Wind	Does not produce substantial amounts of solid waste

Table 3: Waste Generation Created by Each Fuel Type
Source: Author, with data from NEI, Union of Concerned Scientists, and EPA, 2013

Once the countries are interconnected, they could start to rely on others as a source of electricity and start shutting down power plants that produce hazardous and solid wastes, starting with the most detrimental generation facility. For example, as shown in the table above, both coal and nuclear have waste generated after a year of operation. Because coal has tons of waste generated and the waste generated by nuclear is radioactive, a shift can be made away from nuclear and coal to natural gas and other renewable energy sources, ones that do not produce substantial amounts of solid waste. However, this shift can only be made if waste generation is the only issue.

Lastly, land use is another unavoidable environmental issue that arises from the international interconnection. The main impact from land use comes during the construction phase, considering that the power plants are already in place. The use of land would be mainly used for the construction of transformers, converter stations, and transmission towers/lines. However, a potential benefit is the reduced investment in generating capacity. Because of the interconnection, countries have the option to rely on other countries for electricity. This diminishes the need to build extra generating facilities, which use a lot of land, especially hydroelectric plants. However, if a country decides to export electricity and thus builds more generating facilities, this can lead to an environmental impact.

4. Issues

4.1 Technical

With advances to modern technology, there are no real technical reasons as to why the interconnection will not work. The only issue has to deal with North Korea's unknown power system. North Korea has a power grid in place, however, the status of it is unknown, though it is assumed to be decrepit and in need of repair or a new transmission system may need to be installed altogether.[11] Before North Korea can be interconnected with its neighbors, it must repair, upgrade, or install a new transmission grid in order to be able to handle the increased loads going in and out of the country.

One possible solution that would help stimulate the repair or construction of a new power grid in North Korea would be to implement a loan-type incentive. Neighboring countries (China, Japan, South Korea, and Russia) would help to purchase the materials and possibly also provide the labor to repair or construct a new grid. After construction is finished, North Korea would pay either with currency or with electricity. This would not only help North Korea adopt a functioning power system; but, also improve relations with all of the countries.

4.2 Economic

There are several cost factors that are unavoidable when building the interconnection. One obvious unavoidable cost is the construction of the interconnection itself. However, there may be ways to mitigate the total cost of the project. One such way is to utilize the Clean Development Mechanisms of *the Kyoto Protocol to the United Nations Framework Convention on Climate Change*. This mechanism essentially credits nations every time they reduce one ton of carbon dioxide.[12] Another possible solution to reduce costs is to have countries cooperate with each other. For example, a country can provide materials while another can provide labor. Not only would this help with mitigating the costs of building the interconnection; but, it would also help foster good relations with each of the countries.

[11] Yoon, 2011
[12] United Nations, 2013

Another unavoidable cost is the cost of fuel to generate electricity. Again, this cost is quite obvious, as generation facilities require fuel in order to run and these fuels cost money, with the exception of renewable energy sources. However, a simple solution to this cost is to simply use generation facilities that have cost-effective fuel sources, such as renewable energy and nuclear.

4.3 Environmental

Initially, the environmental impacts of building the interconnection are unavoidable. These impacts include air, water, solid and hazardous waste generation, and land use. Greenhouse gas emissions from construction vehicles are the main source of air pollution due to construction. Water pollution consists of erosion from soils stripped of vegetation and access road construction; heavy machinery operation and leakage in rivers and wetlands; and accidental spills from other emissions of liquids.

Solid waste generation comes from the removal of rock, dirt, trees, and other materials and biomass to install power line towers, converter stations, and substations. Hazardous waste generation may come from the removal of older equipment, such as old transformers and converter stations that have to be upgraded in order to be able to handle the increased load.

Lastly, the construction of transformers, transmission lines, and converter stations require the use of land and therefore, space must either be found or created to make the interconnection possible. While the air and water construction impacts along with the waste generation are transient and therefore, are short term, the land use is permanent. However, while land use is unavoidable, finding a site that is the least detrimental to the surrounding environment would greatly mitigate the impact a building or structure will have.

As mentioned before, the main areas of environmental benefits come from the deciding which generation sites to use. If the focus is purely on environmental factors, a generation site would run or stop running, depending on how much of an environmental impact the site would have. However, this exact way of trying to figure out which generation site would be more beneficial to use can also cause severe impacts to the environment. In order to prevent this from happening, further research is needed before any decision is made.

5. Previous International Interconnections

5.1 ENTSO-E

The European Network of Transmission System Operators for Electricity, or ENTSO-E, is a conglomerate of six previous associations: the *Association of the Transmission System Operators of Ireland* (ATSOI), the *Baltic Transmission System Operators* (BALTSO), the *European Transmission System Operators* (ETSO), Nordel, and the *Union for the Coordination of the Transmission of Electricity* (UCTE), and the *UK Transmission System Operators Association* (UKTSOA).

ENTSO-E was started in 2008 when the CEOs of 36 European Transmission System Operators from 31 countries signed a Declaration of Intent.[13] ENTSO-E became fully operational on 01 July 2009 with 42 TSOs from 34 countries.[14] The following figure shows the energy flows of countries that are and are not in ENTSO-E.

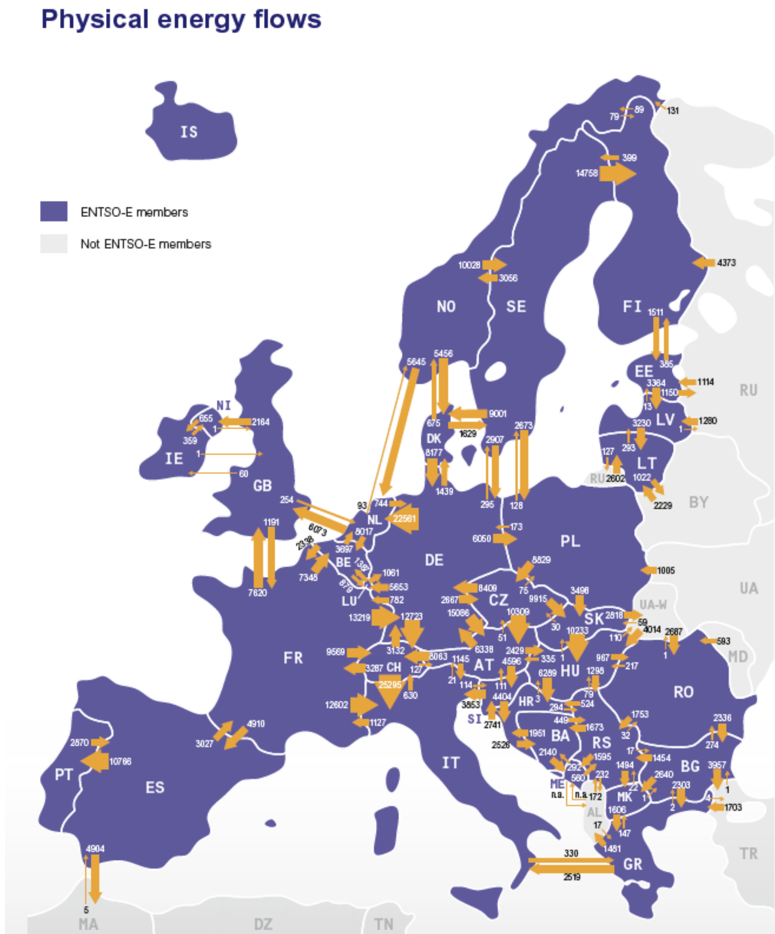

Figure 15: Energy Flows of ENTSO-E members and non-members
Source: ENTSO-E

As shown in the figure, every country in Europe, with the exception of Iceland and Cyprus (not shown), trades electricity. One of the reasons for this massive transmission system functionality is due to transparency. The ENTSO-E developed a Transparency Policy for every

[13] ENTSO-E, 2008
[14] ENTSO-E, 2009

member to follow to ensure a well-functioning, efficient, liquid, and competitive wholesale market (Transparency Policy). Since its conception, the ENTSO-E has provided monthly statistics about its member countries, system development reports, system operations reports, and market reports, which include tariffs and compensation.[15] Additionally, the ENTSO-E has an Electronic Data Interchange Library, which contains all documents and definitions approved by the ENTSO-E.[16] With this sort of transparency, countries that are members in the ENTSO-E can function cooperatively and competitively.

Another benefit the ENTSO-E interconnection has provided is the complementation between countries. The following figures show the energy flows between Spain and France in January and February.

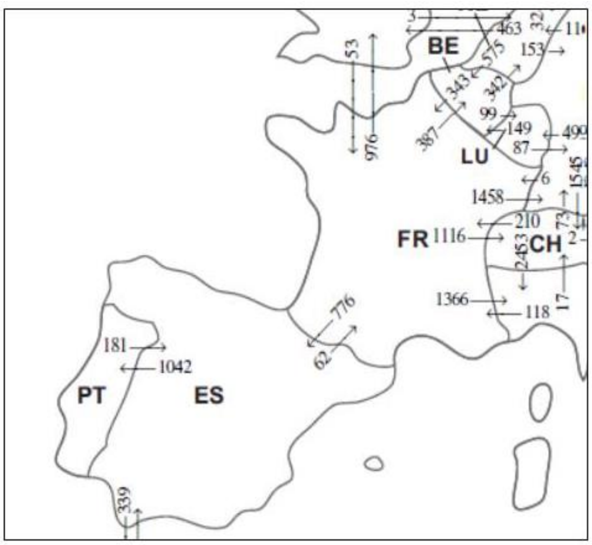

Figure 16: Energy Flow in January in GWh
Source: ENTSO-E

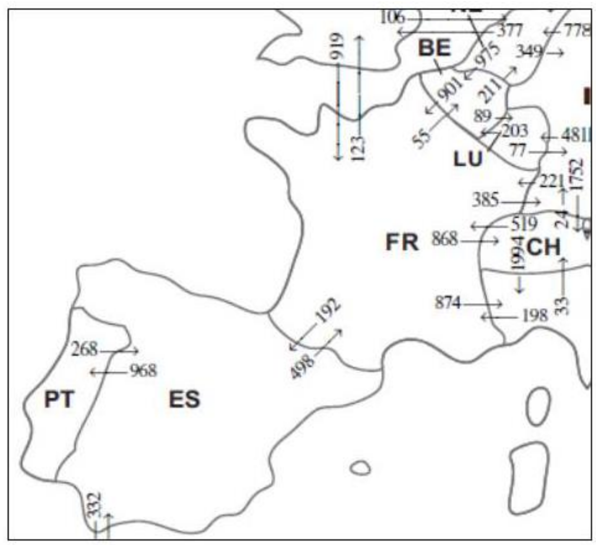

Figure 17: Energy Flow in February in GWh
Source: ENTSO-E

In Figure 16, a net total of 714 GWh flows from France to Spain during January while in Figure 17, a net total of 306 GWh flows from Spain to France during February. In this example, France helps alleviate the loads Spain has during January and the roles are reversed during February. This sort of sharing occurs throughout Europe, where one country helps another and in turn, gets helped when in need.

5.2 North America

[15] ENTSO-E, 2013
[16] ENTSO-E, 2013

Another successful international interconnection comes from North America, where HVDC lines connect the United States and Canada. The following figure shows the locations of these interconnections.

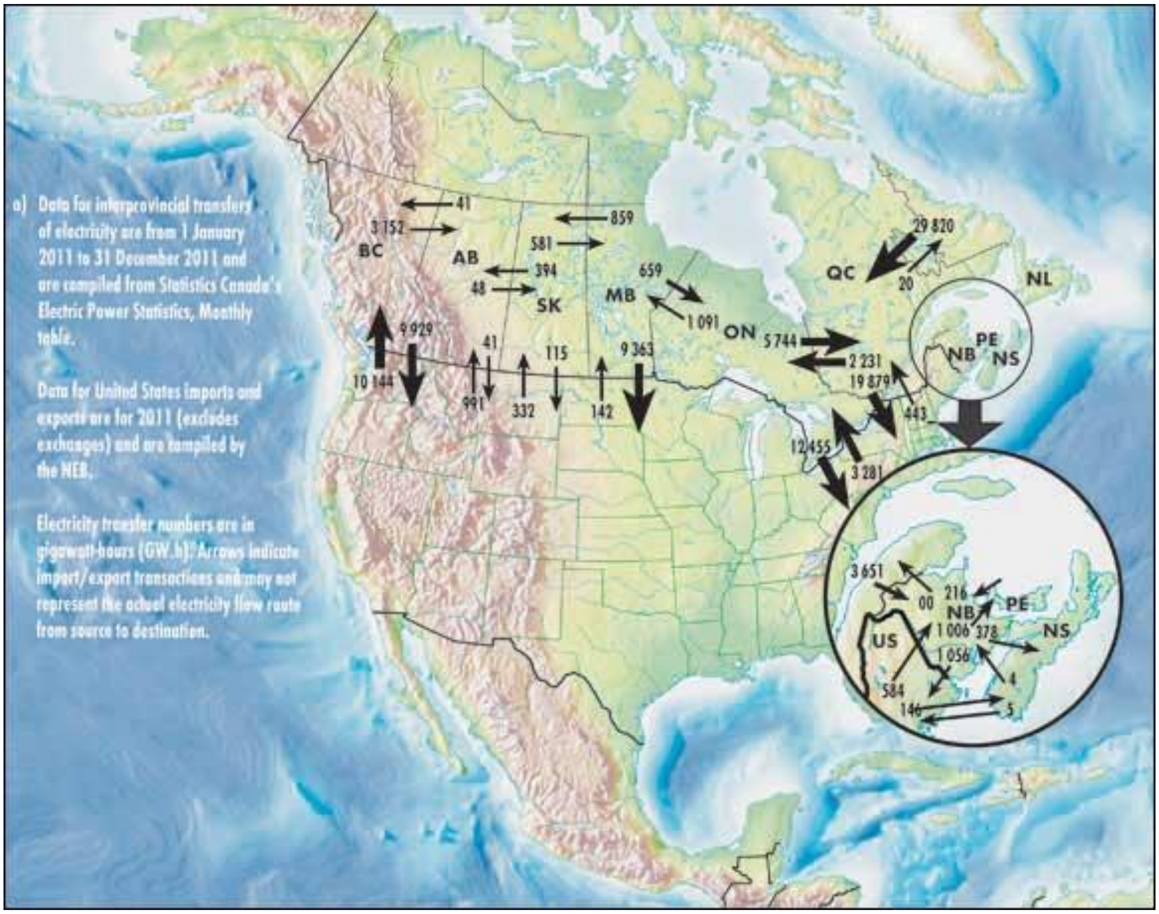

Figure 18: Canada and United States Interconnections
Source: NEB

Since 1990, Canada and the United States have been trading electricity. In 2008, Canada exported 55.7 TWh to the United States at an average rate of $0.065 per kWh while the United States exported 23.5 TWh to Canada at an average rate of $0.057 per kWh.[17] While Canada's export of 55.7 TWh of electricity may seem miniscule compared to the United States' 4,119 TWh of electricity generated, this energy export greatly benefits the importing area.[18] For example, in 2008, New York consumed approximately 144 TWh of electricity. Canada exported approximately 16.8 TWh of electricity, accounting for 11.7% of New York's electricity requirements. Canada has also helped Michigan with 6% of its electricity being imported from

[17] Goodman, 2010
[18] U.S. Energy Information Administration, 2013

Canada.[19] [20] Additionally, Canada exports its electricity to many states, such as California, Alaska, Washington, and others.

Additionally, The Canada-United States Interconnection has greatly benefited both sides. This is the result of having different generation resources at the disposal of each country. Canada uses hydroelectricity and nuclear as its primary generation sources while the United States uses fossil fuels, such as coal and natural gas, as its primary generation sources. This mix of resources has helped both countries in times of need. In 1989-1990, Canada suffered a severe drought near Ontario and thus lost a majority of its generation capability due to the loss of hydroelectric plants. As a result, New York became Ontario's primary exporter of electricity during the drought.

This generation mix has also helped New England, due to high electricity costs from coal-fired and nuclear plants. Importing electricity from New Brunswick and Quebec became a more cost-effective solution. In the late 1980s, excess capacity of low-cost coal generation allowed Michigan to export electricity to Ontario. Similarly, Manitoba had an excess capacity of low-cost hydroelectric generation which led it to export electricity to Minnesota.[21] This symbiotic relationship between the United States and Canada has helped the two countries in times of need.

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[19] U.S. Energy Information Administration, 2010
[20] National Energy Board, 2010
[21] Wang, 2000

6. Conclusion

The interconnection among the five countries in East Asia is just a starting point to a fully interconnected world. With a world-wide interconnection, every country would benefits. However, before the world can be interconnected, it would be ideal to start connecting on a smaller scale, such as among several countries. Once the interconnections have been established and are stable, more countries can be added to the network. Eventually, all countries should become interconnected and world-wide sharing of electricity would occur.

This paper was a cost/benefits analysis on an international interconnection among five countries in East Asia. With our current technology, an interconnection is technically feasible. Despite its costs, an interconnection is technically, economically, socially, and environmentally beneficial to each country. Examples from North America and Europe show that an international interconnection between not only two countries but also among countries in an entire continent is possible.

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