

Environmental Impacts and Benefits of Regional Power Grid Interconnections for the Republic of Korea

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ABSTRACT: This paper provides rough estimates of the environmental benefits, from the standpoint of the Republic of Korea, of power system interconnection among Northeast Asian countries (referred to here as NEAREST for North East Asian Region Electrical System Ties). Emphasis is placed on potential “RFE-DPRK-ROK” (Russian Far East—Democratic Peoples' Republic of Korea—Republic of Korea) inter-ties. The estimates presented here are based on several previous specific case studies, including an earlier KERI interconnection scenario and a new scenario including the effect of the KEDO N/P (Korean Peninsula Development Organization nuclear power plants) that are being built in the DPRK. Generally, it is known that power system interconnections between countries, each one of which has their own seasonal load maximum, power mix, and electricity tariffs, has advantages from environmental as well as economic viewpoints. The environmental benefits of power system interconnection include the reduction, through the mechanism of inter-country electricity trading, of GHG (Green House Gas) emissions from electricity production in thermal power plants. The monetary value of the avoided emissions can be expressed as the total reduction in GHG emissions multiplied by a CO₂ tax per TCE (Tonne of Carbon Equivalent). This paper describes the results of the analysis of environmental benefits, including reductions in TCE and in CO₂ taxes, that could be obtained using inter-country electricity trading based on “RFE-DPRK-ROK” power system interconnection scenarios.

KEY WORDS: power system interconnection, electricity trading, economic benefits, environmental benefits, NEAREST

1. Introduction

Since the 1990s, many papers have been published on the topic of power system interconnection among the Northeast Asian countries, or NEAREST. In the early stages of the evaluation of interconnection potential, analyses mainly focused on economic costs and benefits. After the Kyoto protocol to the United Nations Framework Convention on Climate Change was agreed to in 1997, however, the environmental problem of GHG emissions has

become a topic of serious national concern in the ROK. All of the countries that agreed to the protocol are expected to reduce their emissions of GHGs such as CO₂, SO_x and NO_x to the emission level of an earlier year (for example, 1990) by a specific target year. This environmental duty will have an influence on the whole economic sector in almost all of the countries, especially in that most countries would be expected, in the absence of very stringent policies, to increase their amount of GHG emissions in the coming years. Given this background, some countries, especially the ROK with its higher economic growth rate, may find Kyoto emissions reduction targets to be more difficult to deal with than will other countries.

In 2002, the total amount of electricity production in the ROK was about 303 TWh (Terawatt-hours), and the share of electricity provided by thermal plants, power plants (those fueled with coal, oil, and gases) that produce GHGs is 58 percent. In the ROK, the power industry's share of total national GHG emissions is about 25 percent. This is rather higher than in other countries. Also, according to the 1st future electricity demand and supply prospect published by MOCIE (Ministry of Commercial, Industry and Energy of ROK) after power industry restructuring in the ROK, ROK electricity demand is expected to increase continuously at a rate of about 4% annually from 2002 to 2015. As a consequence, countermeasures to reduce GHG emissions in the power sector are an important topic for the Korean government.

Electricity trading between countries can be a good countermeasure to reduce GHG emissions. Such trading offers two distinct environmental benefits. First, electricity trading can result in the substitution of cleaner fuels for the coal that is the most popularly used fuel for power generation in NEA (the Northeast Asian region). If the electricity generation to be sold through the interconnection can occur in places where cleaner fuels are more plentiful (whether generation is from natural gas, hydro, nuclear, or other renewable energy sources), then the total amount of emissions from the power industry can be decreased. Second, power exchange via NEAREST can help to establish the infrastructure to open an emission trading market among the countries of NEA. An emissions trading market can be in the economic interests of all partners, as the mutual trading of allowed emission amounts among countries can take place based on whether the countries can comply with emissions restrictions or not.

Fuel switching or altering the mix of fuels used region-wide via electricity trading among the countries so as to produce less CO₂ emissions per unit of electricity, will result in further decreasing the “carbon intensity” of the power generation sector. Basically, the key environmental benefits of these interconnection scenarios are the reduction of electricity production in thermal power plants as a result of the use of the inter-country interconnection.

This paper therefore investigates the environmental benefits of specific interconnection scenarios. Analytical results showing the reduction in the amount of TCE and CO₂ tax through the power system interconnections are shown for several specific cases.

2. Power Interconnection Scenarios for “RFE-DPRK-ROK”

Many scenarios for NEAREST have been published by institutes working on power interconnection topics, including as ESI (Energy Systems Institute, Russian Academy of Sciences, Siberian Branch), KERI, and others [1-2]. Most of these scenario analyses, however, have simply estimated the rough parameters of interconnection scenarios, including voltage level, capacity, and line length of inter-ties. The basic contents and concepts covered

by these scenario analyses have been largely similar to each other. This paper presents a new interconnection scenario including the KEDO N/P that is different from the existing interconnection scenario such as the previous KERI and ESI scenarios for “RFE-DPRK-ROK” interconnections.

2.1 Potential local interconnections under discussion

Several meetings on an inter-governmental basis have been held since 2001 to discuss the realization of local power interconnections between neighboring countries in NEA. The power system interconnections discussed are as follows.

- 1) Russia has a plan to interconnect its power grid with that of the DPRK. This interconnection might ultimately be extended to the ROK. A number of problems, however, including obtaining financing, pose significant barriers to this project. Elements of this interconnection plan are:
 - The project will include a 380km, ± 500 kV DC Line between VLADIVOSTOK and CHEONGJIN
 - The line will be operated at 220 kV AC during the first stage of the project, and will be changed to 500 kV AC operation after the 500 kV line between “CHUGEVKA-NAHODKA-VLADIVOSTOK” is put into operation in the south of the Primorye region of the Russian Far East. In its final stage, the line would be modified as a ± 500 kV HVDC line in the future.
- 2) The ROK and DPRK seek to develop an industrial complex at GAESUNG, near the shared border of the two countries (but inside the DPRK). The required electricity for the DPRK's portion of the development might be supplied by the ROK.

This project is utterly dependent on the political situation between the two parties. Some of the proposed parameters of the project are:

- Transmission capacity: short-term 100-200 MW (25-40km)
- Transmission voltage: uncertain (possibly 154 kV or higher)

2.2 New scenario including KEDO N/P

Basically, in the authors' opinions, there are several possible types of scenarios for a “RFE-DPRK-ROK” interconnection. In order to include the KEDO N/P in a power interconnection network, we can consider the interconnection route “VLADIVOSTOK-SINPO” as a tentative hypothesis. This scenario is somewhat different from the existing scenario for a “VLADIVOSTOK-CHEONGJIN” interconnection that is under discussion between Russia and the DPRK.

The “VLADIVOSTOK-SINPO” scenario could be one of the alternatives for the effective utilization of the KEDO N/P. If this scenario is implemented, after the commissioning of KEDO N/P by means of the interconnection the DPRK can earn revenues by trading seasonal surplus electricity, or can be supported with electricity imports at times of seasonal shortage of electricity. This means that all of the interconnected countries in this scenario can reap benefits by trading seasonal surplus electricity.

3. The Power industry and GHG emissions in the ROK

3.1 The Power industry in the ROK

Table 1 describes the present status and future projections for installed generating capacity in the ROK. Currently, the installed capacity is 53,801MW and capacity is expected to rise to 77,024MW by 2015. In terms of the plant mix, the share of oil and coal plants are projected to decrease over the next 12 years, but the share of nuclear capacity is projected to increase.

Table 1: Present and Future Projected Generating Capacity in the ROK (MW)

Year	Nuclear	Coal	Gas	Oil	Hydro	SUM
2002	15716 (29.2%)	15931 (29.6%)	13618 (25.3%)	4660 (8.7%)	3876 (7.2%)	53801
2005	17716 (28.6%)	18165 (29.4%)	16814 (27.2%)	4667 (7.5%)	4485 (7.3%)	61847
2010	23116 (29.3%)	24265 (30.7%)	20437 (25.9%)	4817 (6.1%)	6385 (8.1%)	72635
2015	26637 (34.6%)	22240 (28.9%)	19550 (25.4%)	2212 (2.9%)	6385 (8.3%)	77024

Table 2 describes the present and future total electricity production in the ROK. As shown in this table, the expectation is that the portion total generation provided by nuclear power plants will rise slightly in the future. In contrast, the fraction of generation provided by thermal plants such as coal- and oil-fired units will decreased.

Table 2: Present and future Projected Electricity Production in the ROK (TWh)

Year	Nuclear	Coal	Gas	Oil	Hydro	Etc.	SUM
2002	122.8 (43.2%)	117.9 (41.5%)	29.7 (10.4%)	26.7 (2.8%)	6.0 (2.1%)	- (0.0%)	344.8
2005	134.1 (40.6%)	132.7 (40.2%)	45.6 (13.8%)	24.8 (2.9%)	6.7 (2.0%)	1.4 (0.4%)	399.0
2010	166.7 (42.1%)	175.2 (44.3%)	26.5 (6.7%)	17.9 (4.5%)	8.5 (2.2%)	1.0 (0.3%)	435.0
2015	210.3 (47.2%)	165.4 (37.1%)	49.0 (11.0%)	12.0 (2.7%)	9.3 (2.1%)	- (0.0%)	445.9

Although the projections shown in Table 2 indicate that nuclear power's shares of future ROK installed capacity and electricity production are expected to be higher than they are at present, it should be noted that these projections should be considered just long-term targets. Factors such as the shortage of land in the ROK suitable for nuclear plant construction, and public resistance against building power plants, especially nuclear plants

(the "NIMBY", or "not in my back yard" movement) will likely make these targets difficult to achieve.

As a result of the "NIMBY" movement in the ROK and the public fear of atomic energy, construction of new nuclear power plants faces difficulties. Furthermore, building thermal power plants fueled with coal, oil and gas is problematic because of the constraints on GHG emissions specified under the Kyoto protocol. Therefore, as a matter of government policy, it is necessary to establish a future general plan and countermeasures that will help to assure that future electricity demand is met while still reducing GHG emissions.

3.2 Power industry and environmental impacts

Table 3 provides data published by KOGAS describing the environmental impacts of electricity production of 1GWh for each major power plant type.

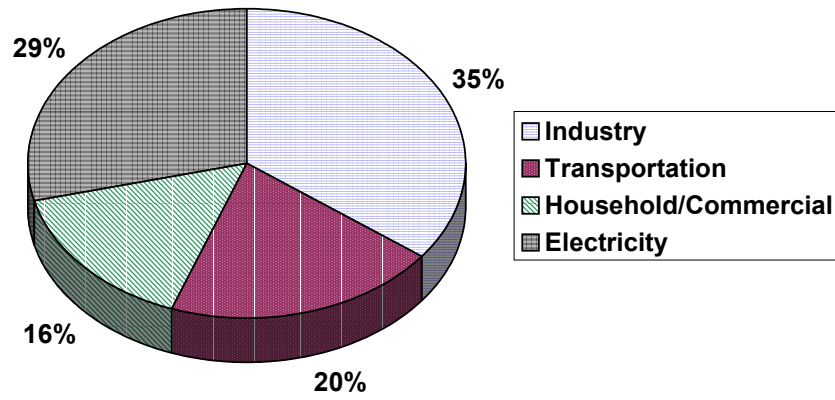
Table 3: Environmental Impacts by Plant Type for Production of 1GWh of Electricity [4]

Item	LNG	Coal	B-C Oil	Nuclear
Global warming (kg CO ₂ ^{-equiv})	CO ₂ 6.23×10 ⁵	CO ₂ 9.24×10 ⁵	CO ₂ 7.49×10 ⁵	CO ₂ 9.21
Ozone depletion (kg CFC11 ^{-equiv})	Halon 1.22×10 ⁻³	Halon 2.75×10 ⁻³	Halon 3.92×10 ⁻¹	Halon 3.55×10 ⁻⁸
Acidification (kg SO ₂ ^{-equiv})	SO _x 4.21×10 ²	SO _x 2.87×10 ³	SO _x 2.52×10 ³	SO _x 4.73
	NO _x 7.01	NO _x 1.33×10 ³	NO _x 1.52×10 ³	NO _x 2.38
Eutrophication (kg Phosphate ^{-equiv})	NO _x 1.30×10 ²	NO _x 2.47×10 ²	NO _x 2.82×10 ²	NO _x 4.42×10 ⁻¹

Table 3 shows that electricity production is a major contributor to various environmental problems, including global warming, ozone depletion, acidification, and eutrophication. The data provided for each plant type show their impacts on the environment per unit electricity output, which allows an assessment of how much each plant type affects the environment relative to other generation options. As shown in Table 3, the nuclear plants have the smallest environmental impact on each of the parameters shown, and coal-fired power plants produce the most serious emissions. Among the different species of GHGs emitted by fossil-fueled power plants, CO₂ causes the most serious problems because of its high concentration in both the atmosphere and in power plant exhaust gases.

The power industry is the one of the main sectors contributing to GHG emissions in ROK; its share of emissions is about 25% at present. As an example focusing on CO₂ emissions, Figure 1 describes the present and projected future (2015) CO₂ emissions in the ROK by major source of emissions. This figure shows that the electricity sector contributes about 29% of CO₂ emissions in 2000. In the future it is expected that the share of total ROK energy use provided by electricity will increase. As a result, the share of CO₂ emissions from the electricity sector will become higher than it is currently. Figure 2 shows the present and projected level of CO₂ emissions per kWh of electricity generated. This figure shows that CO₂ emissions per kWh will gradually decrease in the future.

Year 2000



Year 2015

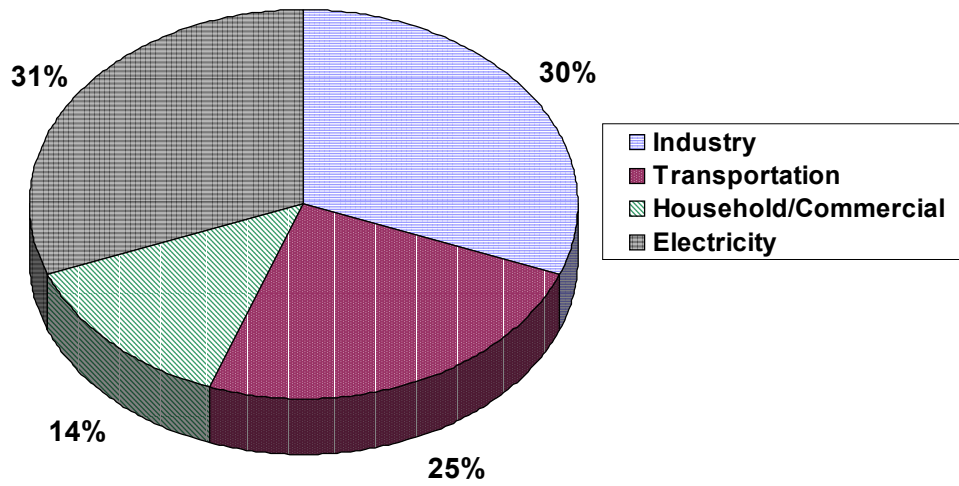


Figure 1: Present and Future Projections of CO₂ emissions by sector in the ROK

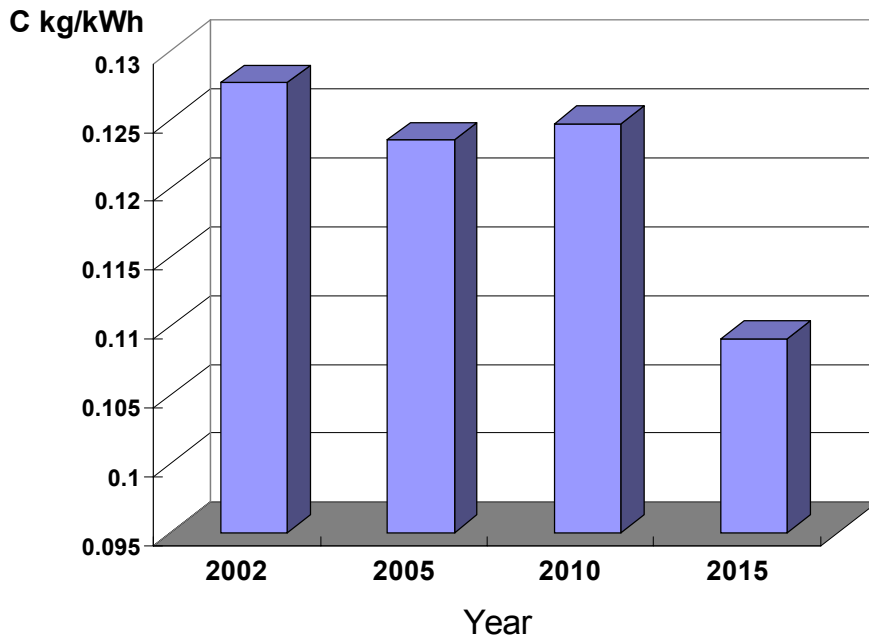


Figure 2: Present and Future Estimates of CO₂ emission per kWh Electricity Generated in the ROK

In countries where a high proportion of electricity is provided by thermal power plants, GHG emissions restrictions under the Kyoto protocol will affect overall national economic behavior. In light of governmental policy, countermeasures to reduce the GHG emissions in the power sector should therefore be established before implementing the Kyoto protocol. If electricity trading between a country where the dominant portion generation is provided by hydro or nuclear plants and a country that uses thermal plants heavily is set up to take advantage of seasonal load curve variations between countries, the result will be advantageous to the environment by reducing the total amount of GHG emissions, in addition to providing economic benefits. Power system interconnections among Northeast Asian countries, NEAREST, can utilize this type of trading arrangement, and thus can provide a means of reducing the environmental impacts of GHG emissions.

4. Environmental Benefits of Interconnection Scenarios: Analytical results

In this paper the environmental benefits of two specific scenarios for “RFE– DPRK– ROK” power system interconnection are analyzed. This paper does not quantitatively evaluate scenarios that integrate long-term cooperation policies and local power system interconnections, such as the “VLADIVOSTOK-CHEONGJIN” and “ROK-GAESUNG” inter-ties (noted above) that are under discussion. Those scenarios may be analyzed in the future. The specific “RFE– DPRK– ROK” interconnection scenarios under study here are as follows.

- The previous KERI study scenario (route and capacity as shown in Figure 4);
- A new scenario including the KEDO N/P (as shown in Figure 6); and
- A scenario for future analysis integrating the long-term cooperation policy and local

planned interconnections (Figure 8).

4.1 Analysis method

In this paper, the analysis method used to estimate the environmental benefits of NEAREST is based on that described in a previous KERI report that documents research sponsored by KEPCO [1]. In the previous KERI report, one of the sub-topics covered is an economic assessment of NEAREST. Rough economic benefits were calculated based on hypothetical interconnection scenarios. Figure 3 describes the general procedure of economic assessment used, including the required data, and the benefit and cost evaluation components. In addition, the assessment calculates estimated environmental benefits. This preliminary economic assessment model for power system interconnection is implemented using a simple MATLAB program developed by KERI. The output of the MATLAB program is the net electricity imported into the ROK under a specific scenario, that is, total imports minus total exports of electricity during each year. The analysis period for calculation of environmental benefits in the study is from 2002 to 2015. The years "2002" and "2015" are not necessarily fixed dates, however, and can be interpreted as "Year 1" and "Year 14" of the operation of the inter-tie as applied to calculate the environmental benefits of power system interconnection.

The environmental benefits in each year are calculated as described in equation (1) using the net imports of electricity into the ROK. In equation (1), the symbol i is restricted to thermal plants (coal-, oil- or gas-fired), and does not include hydro or nuclear plants. Most of the generating capacity that can be avoided due to power system interconnection are thermal plants in the ROK. In contrast, most of the increase in capacity (in order to generate power for export) in other countries involved in the interconnection—for example, Russia—is expected to be in non-thermal plant types such as hydro and nuclear. As a consequence, the maximum environmental benefits of power system interconnection in the ROK can be estimated using equation (1), which only includes the share of thermal plants in power production.

$$EB \text{ (Environmental Benefits)} = \sum_i [IE \times Sh_i \times puTC_i \times \$TCE] \quad (1)$$

Where,

IE: Net Imported Electricity into ROK (kWh)

Sh_i : Share of each plant type i in electricity production (%)

$puTC_i$: Equivalent carbon emissions per kWh for each plant type i (TCE/kWh)

(i : only thermal plants fired with coal, oil, or gas, not hydro or nuclear plants)

$\$TCE$: Carbon Tax per Ton Carbon Equivalent (\$/TCE)

Basic Data	<p style="text-align: center;">Input data for economic assessments</p> <ol style="list-style-type: none"> 1. Period of study, rate of return 2. Target ratio of supplying reserves and installed capacity 3. Alternatives for the interstate electric ties <ul style="list-style-type: none"> - Capacity, line length, routes - Construction costs of C/S (Converter Station) in \$/MVA - Construction costs of T/L (Transmission Line) in \$/km 4. Parameters for interconnected system operation <ul style="list-style-type: none"> - Availability, loss rates of C/S and T/L as a percentage of transmitted power (MW) - Annual operation and maintenance costs of interconnected electric ties 5. Future projections of peak load for all concerned countries <ul style="list-style-type: none"> - Seasonal average load curve - Average electricity charges in \$/kWh - A power exchange model among the concerned countries 6. Environmental costs such as CO₂ taxes. 7. Other data
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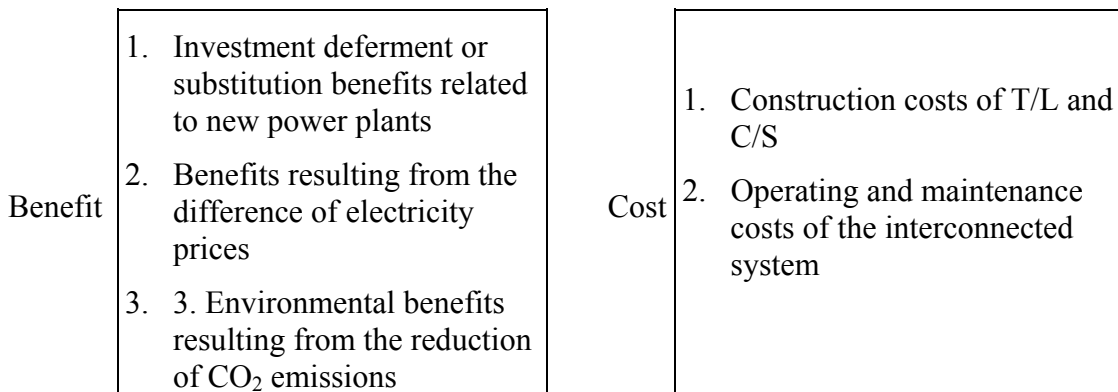


Figure 3: Components of economic assessment for power system interconnection

A key parameter in equation (1) is the estimate of \$TCE (carbon tax per tonne carbon equivalent). At this time, there is no market-based value for this parameter, a CO₂ market in the NEA region is conceivable in the distant future. Many reports describing prospective CO₂ taxes, however, suggest that a CO₂ tax is likely to be \$US10/TCE or higher [7]. We can therefore assume a CO₂ tax of \$10/TCE. Of course, the CO₂ tax could in practice be higher or lower in the future than we have assumed. In New Zealand, for instance, the CO₂ tax will be \$US12 /TCE after 2007 if the Kyoto protocol is implemented.

4.2 Analysis results

(1) Case-1: Previous KERI scenario for “RU-DPRK-ROK”

This scenario is one of the interconnection scenarios presented in a previous KERI study, and does not consider integration of the KEDO N/P. The overall configuration of the interconnection assumed in this scenario is the 3GW, DC $\pm 500\text{kV}$ 1200km line described in Figure 4. The net electricity imported into the ROK in this scenario is 11.17TWh annually, and the current shares of coal, oil and gas generation in the total electricity production mix of the ROK are applied to calculate the environmental benefits of the interconnection. The analytical results of this case are described in Figure 5. Figure 5 shows that the amount of CO₂ emissions in the ROK are reduced by 6.5MTCE/year in 2002, an amount equivalent to 4.8% of total GHG emissions in the power sector as of the year 2002. This emissions reduction equates to savings on CO₂ taxes (in 2002) of \$65M/year, based on a CO₂ tax of \$10/TCE. Savings increase over time as shown in Figure 5.

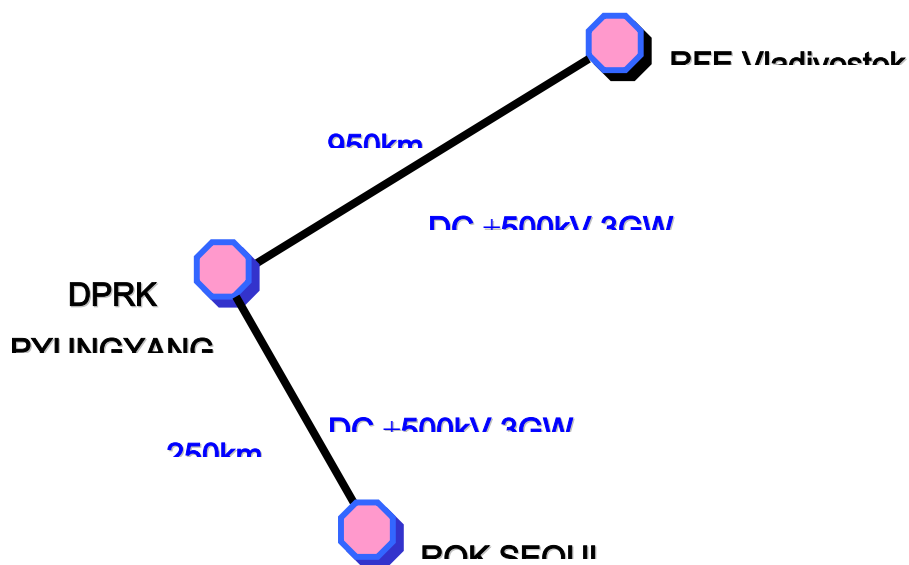


Figure 4: KERI's Previously Published Scenario for “RU-DPRK-ROK”

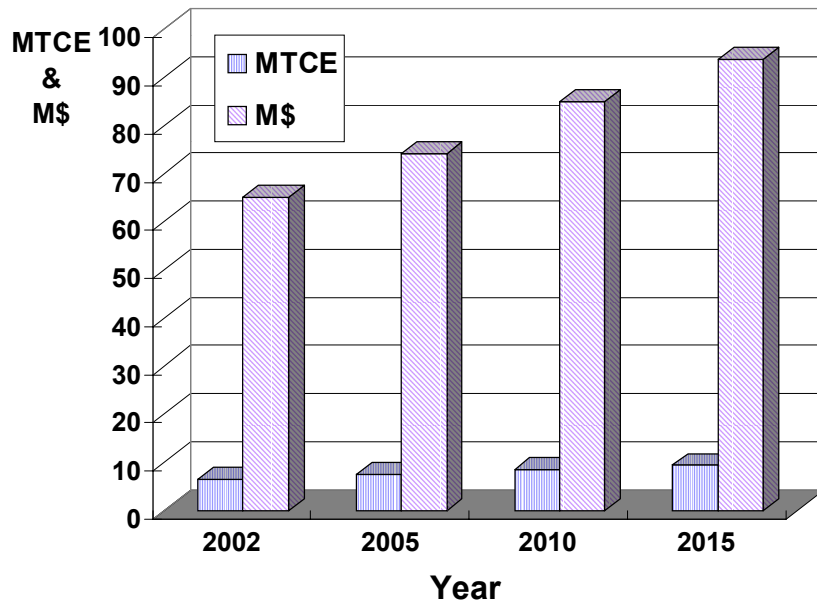


Figure 5: Analysis Results for Case-1

(2) Case-2: New scenario including KEDO N/P

In addition to the transmission line configuration included in case 1, this interconnection scenario includes the KEDO N/P. Figure 6 describes the results of the analysis of Case-2. In this scenario, the net electricity imported into the ROK from Russia is expected to increase (relative to Case-1) because the electrical load of DPRK is met to a greater degree than in Case-1 through the use of the KEDO N/P. Figure 7 shows that the CO₂ emissions reduction due to the interconnection is 9.0TCE/year in 2002, which equates to 6.6% of of the 2002 GHG emissions in power sector. This emissions reduction yields a savings on CO₂ taxes in 2002 of \$90M/year, with savings increasing in future years as in Case-1.

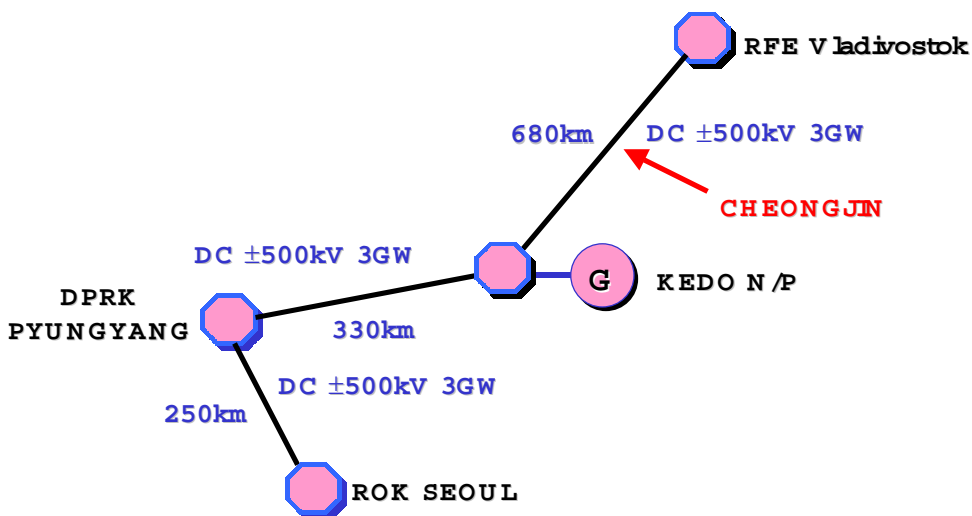


Figure 6: New Scenario Including the KEDO N/P

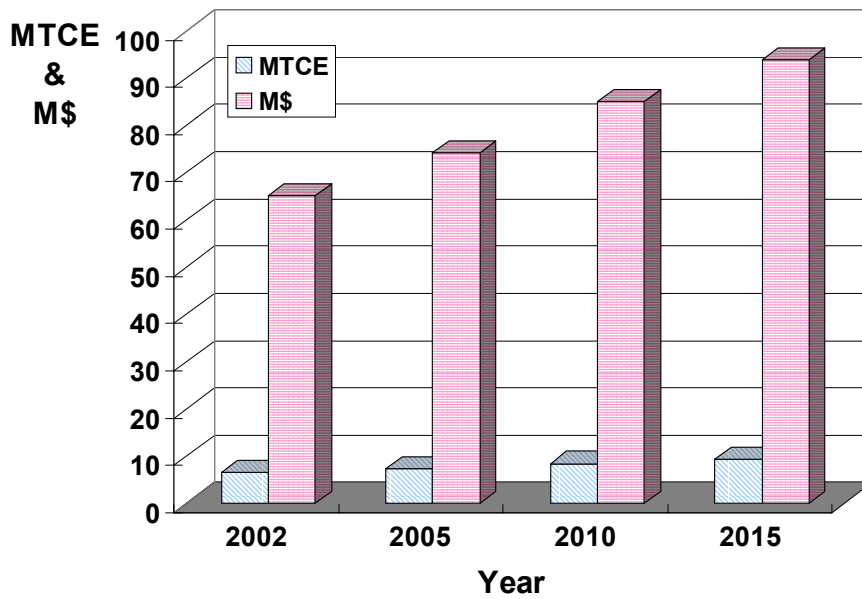


Figure 7: Analysis Results for Case-2

There could be several sub-scenarios for the interconnection in Case-2, differing according to interconnection points, capacity, and voltage class and type (AC/DC). The possible variants for specific sub-scenarios are quite complex. In addition, means of harmonizing different cooperation policies or plans with interconnection opportunities should be studied. For instance, in looking at the longer-term prospects, the electricity supply plan for the GAESUNG industrial complex should be evaluated in a way that also takes into account the opportunities offered by an interconnection scenario such as “VLADIVOSTOK-CHEONGJIN”. All of these analyses remain to be studied in the future. Figure. 8 provides schematic examples of a potential future scenario.

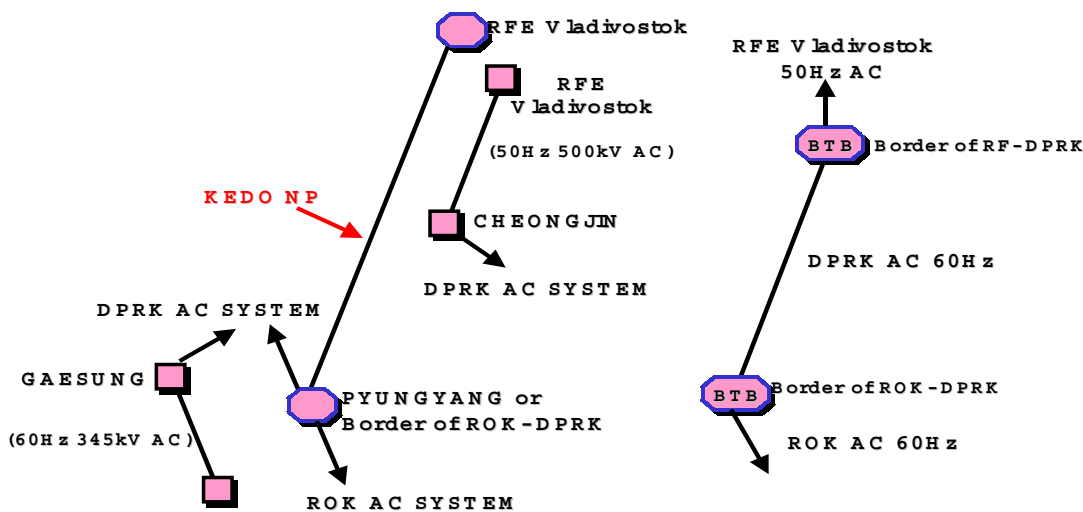


Figure 8: Example case for potential Future Interconnection Scenario

5. Conclusions

In this paper, the environmental benefits based on two specific scenarios for “RFE-DPRK-ROK” power system interconnection are investigated. The results of these analyses demonstrate that power system interconnection can be an effective countermeasures to curb the ROK's GHG emission, thus providing benefits the environmental point of view. In other words, electricity trading between countries using thermal and non-thermal power plant can offer advantages from an environmental, as well as an economic, point of view. Future studies with more detailed scenarios incorporating the KEDO N/P are necessary, and future scenarios should be evaluated that stress the harmonization of regional-scale interconnection possibilities with proposed local cross-border interconnection plans.

6. References

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