ENVIRONMENTAL IMPACTS AND BENEFITS OF REGIONAL POWER GRID INTERCONNECTION FOR THE RUSSIAN FAR EAST: GENERATION AND FUEL-SUPPLY-RELATED IMPACTS

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1. Introduction

Electric power grid interconnections can cause environmental impacts of different types. Construction of transmission lines requires felling trees in the transmission corridor, changes landscape, and has other impacts. Operating transmission lines induce electromagnetic fields affecting plants, animals and human beings.

Transmission losses in the process of power exchange via interconnections require additional power generation and therefore may result in additional emissions of harmful gases from thermal power plants that are additionally loaded. Thermal power plants usually have the largest share in the generation capacity mix of power systems in Northeast Asia. As a result, thermal plants will be required to meet a larger part of any additional power generation. This impact depends on the particular interconnection case, however.

Countries that are exporters of electricity, producing additional generation for export as a result of the interconnection, also are affected by the need for additional power plant construction and operation. The environmental impact of power plants (both during construction and during operation) depends on the power plant type. Thermal power plants (TPPs) release harmful gases while in operation, and occupy land for storage of ash and fuel, and for cooling water ponds. In addition, these TPPs require additional fossil fuel extraction and transportation. Hydropower plants (HPPs) flood land and can cause erosion as their electricity output fluctuates, requiring changes in the rates of water discharge and in the levels of reservoirs as plant output changes. The quality of the water in hydroelectric reservoirs changes in comparison with natural conditions (before construction of the dam). Nuclear power plants impose threat (risk) of radiation release. Nuclear plants also require additional nuclear fuel for operation, storage for radioactive nuclear wastes, and land for cooling water ponds. Construction of all types of power plants affects landscapes and change flora and fauna in the neighborhood of the generation facilities.

On the other hand, power grid interconnection allows large non-fossil fuel power plants (like nuclear, hydro or tidal plants) to be phased in. In quite small power system these plants, if no power interconnections are available, would be constructed in the very distant future when electricity demand on the (non-interconnected) systems become large enough to allow large units and plants to operate in a way that meets reliability requirements. For a large tidal power plant, for example, a large power system is needed to regulate the plant's cyclic output. In particular, large hydropower (for example, pumped-storage) capacity is needed to accumulate tidal plant electricity output during times of the day when the output is not needed (when electricity consumption decreases) and to re-generate the power when it is required. Also, as these large power plants are very capital-intensive, the availability of an interconnection means that their costs can be shared through cooperatively investments by concerned countries-participants in power interconnection. These non-fossil fuel power plants can substitute for smaller fossil fuel power plants (which would be constructed in the absence of a power interconnection) and would reduce harmful emissions from TPPs.

Even without the effect mentioned above, power interconnection provides environmental benefits for electricity importing countries because it decreases their electricity generation. This benefit is particularly valuable in period of maximum load in the importing country, when generating capacity is running at its full extent and therefore environmental pollution is highest.

There may be an additional environmental benefit from power interconnections. Power interconnections result in load curves in the interconnected countries that are "flatter" (have more base load zone and less peak zone) in comparison with load curves of separate power systems. This increases the share of base load power plants and decreases the share of peak load power plants in the generating capacity mix of interconnected power system as a whole. If peak power plants are replaced by base load plants (including nuclear and hydroelectric plants) in an interconnected power system the result is a decrease in harmful air pollutant emissions from the (typically TPP) peak power plants that are run less often. If the base load plants being phased in are thermal plants, this replacement also may decrease harmful emissions somewhat because the thermal efficiency of base load thermal power plants is usually higher than that of peak load plants (provided that the base and peak load plants considered are of the same type).

2. Setting the problem and assumptions

The environmental impact/benefit for the Russian Far East (RFE) power system as a result of its interconnection with the DPRK (Democratic People's Republic of Korea) and ROK (Republic of Korea) power systems was studied on the basis of the results obtained in the work described in the document "Studies of Interstate Electric Ties in Northeast Asia" [2]. This study was conducted in the end of 1990s. Since that time, some conditions changed and new data and circumstances have been revealed. Nonetheless, the results of the study can be use to illustrate the costs and benefits, including environmental costs, of power interconnections in the Northeast Asia (NEA) region.

Studied in [2] were the effectiveness and reliability of "RFE-DPRK-ROK" interstate electric tie (ISETs). The results of this effectiveness assessment were obtained by means of the use of the ORIRES optimization model. This model computed optimal transfer capacities of ISETs, the mix of generating capacities and operating conditions (in terms of merit order loading of power plants) of electric power systems (EPSs), and power exchanges via ISETs. Computations were made for the year 2020. A schematic of a "RFE-DPRK-ROK" ISET is presented at Figure 1.

Figure 1. "RFE-DPRK-ROK" ISET



When studying the ISET's economic effectiveness, computations (by means of the model) were made for two variants of the scheme indicated above: 1) when there was no ISET (separate operation of the EPSs) and 2) when there was an ISET (joint operation of EPSs). Model runs were carried out for both variants, and optimal values of power plant additions, electricity generation, power exchange and the objective function of the model were obtained. The ISET is considered economically efficient if the value of the objective function of the model in the first variant (separate operation) is higher than that in the second variant (interconnected operation). Under these conditions, the costs for separate development and operation of all the EPSs exceed the costs of their interconnected development and operation (including costs for construction and maintenance of the ISET). If this objective is not met, the ISET is economically inefficient.

Comparing results obtained for both variants allows one to estimate the additional generation capacities to be phased in and the power to be produced by different plants, and/or the capacities and power generation to be avoided due to the power system interconnection (PSI). Based on these estimates of additional or avoided capacity and generation, the environmental benefit or impact due to power grid interconnection can be estimated.

Three scenarios of the prospective development of the RFE power system are preliminarily considered in this paper. The first is the Nuclear scenario. The Nuclear scenario supposes that nuclear capacity will be developed in the RFE. The study referred to above [2] was conducted considering this supposition. The second scenario is the Hydro scenario. The Hydro scenario supposes that instead of nuclear capacity hydropower plants will be developed in the RFE. The third is the Fossil fuel scenario, which assumes that coal-fired power plants will be developed in the RFE instead of nuclear and hydropower capacity. All of these scenarios are considered to be quite illustrative. Neither the Nuclear nor Hydro scenarios assume "pure" nuclear or hydro additions. Both nuclear and hydro development are accompanied by development of other types of power plants, in particular, thermal plants. Development of TPPs in the Fossil fuel scenario is also accompanied by some development of hydro power plants. The environmental issues of the RFE power system in view of power interconnection are studied for all scenarios.

The following assumptions were made in preparing this study.

1. Consideration of environmental impact was limited by SO_2 , NO_x , particulate, and carbon dioxide (as carbon) emissions from fossil fuel-burning power plants, and risks (hazard) for human health from fuel cycles including extraction, processing, transportation and storage of fuel, and electricity production.

2. In view of the considerable uncertainty inherent in the analysis, emissions and risks were estimated as ranges (intervals).

3. Estimates of emissions and risks from RFE participation in PSI are obtained for parameters of and power exchange volumes via the ISET that were estimated in the study described in [2]. These estimates will change if different exchange parameters and traded volumes are used.

4. Lacking the required estimates of specific emissions and risks from power plants of RFE available in publications, those estimates were assumed based on analogous plants elsewhere in Russia. In particular, TPPs burning Siberian brown and hard coal were assumed as analogues for RFE coal-fired power plants.

3. Case study

3.1 Nuclear scenario

Under the Nuclear scenario, nuclear generating capacity in the amount of 2 GW is assumed to be installed in Primorye nuclear power plant (PNPP), providing yearly generation of about 14 TWh. Based on the results of study [2], in the variant in which the RFE EPS operates separately, the required nuclear capacity reaches 1.2 GW, while when interconnection of the RFE with the DPRK and ROK is assumed, development of PNPP at its full capacity, that is, 2 GW, is required. Therefore, the "RFE-DPRK-ROK" power system interconnection variant results in an 800 MW nuclear capacity addition in the RFE in comparison with separate operation and development of the RUSSian Far East EPS. Other types of RFE power capacities were not affected by the PSI. In the meanwhile, as can be seen from Table 1, the total generation produced by RFE power plants increases by more than 8.5 TWh in the variant that includes joint RFE, DPRK and ROK operation and development. Thermal, co-generation and nuclear power capacities increase their output. These results mean that the RFE is a net exporter of electricity under the variant.

The disproportion between the relatively small growth of power capacity and the substantial rise of power generation in the RFE in the variant including PSI is due to the fact that a major share of the electricity exports from the RFE take place in summer, when, on the one hand, electricity consumption in ROK is highest, and, on the other hand, idle power capacity in the RFE can produce additional generation for export because RFE consumers at this time experience a seasonal decrease in electricity consumption. The optimal transfer capacity of an ISET from the RFE was estimated to be 4 GW, as can be seen in Figure 1 [2]. This amount of power is exported from the RFE at the time of maximum load on the ROK EPS. 0.8 GW of this amount is provided by additional nuclear capacity developed in the RFE to meet export needs (see above). The rest of the additional peak power exports, 3.2 GW are provided by other existing capacity that is additionally loaded in the summer months (as noted above) and in winter period is used for meeting domestic loads.

Var inte	iant of rconnection	Hydro	Thermal (coal)	Co-generation (coal)	Nuclear	Total
1.	No ISET	12.4	4.9	30.7	8.9	56.9
2.	ISET	12.4	6.15	32	14.9	65.45
3.	Difference	0	1.25	1.3	6.0	8.55
	(1)-(2)					

Table 1: Electricity generation by RFE power plants, 2020, TWh/year

In Table 2, fossil fuel consumption estimates are provided for variants of the scenario including the presence and absence of a power system interconnection. Fossil fuel consumption from this table was calculated assuming specific fuel consumption to be 0.35 kgce (kilograms coal-equivalent)/kWh both for thermal and co-generation coal-fired power plants. Specific fuel consumption for co-generation is usually much less due to the higher thermal efficiency of simultaneous production of electricity and heat. As was already noted, however, a major portion of electricity exports from RFE take place in the summer months when heat consumption is much decreased and co-generation power plants, being additionally loaded to generate electricity for export, operates as conventional thermal power plants producing electricity. The thermal efficiency of co-generation power plants operating under such a regime decreases. The efficiency is roughly estimated to be equal to that of the thermal efficiency of conventional thermal power plants.

Va inte	riant of erconnection	Hydro	Thermal (coal)	Co-generation (coal)	Nuclear	Total
1.	No ISET	0	1.7	10.7	0	12.4
2.	ISET	0	2.15	11.2	0	13.35
3.	Difference	0	0.45	0.5	0	0.95
	(1)-(2)					

Table 2: Fossil fuel consumption by RFE power plants, 2020, Mln. tce/year

As can be seen from Table 2, power exports from the Russian Far East in the case of power system interconnection require the addition of nearly 1 Mln. Tce (tons coal equivalent)/year of coal to fire RFE thermal power plants. This additional coal consumption brings about additional environmental impacts and risks, which are preliminarily assessed below.

Table 3 provides estimates of environmental pollution from harmful gases and particulates exhausted by TPPs [3-5]. RFE TPPs consume both hard and brown coals [6]. The lower end of the range of figures shown in Table 3 characterize emissions from brown coal-fired power plants, and the maximum values of the ranges shown characterize emissions from hard coal-fired power plants. The estimates of SO₂ and NO_x emissions shown in the table are estimated under conditions where no special equipment is installed on TPPs for removal of these oxides from exhausted gases [3].

Pollutant	Emission Factor Range
SO ₂	2.6-3.5
NO _x	1.5-5.0
Particulates	2.7-3.4
Carbon Dioxide, tons of Carbon/tce	0.67

Table 3: Specific emissions from coal-fired TPPs, g/kWh

Table 4 provides estimates of risks (hazard) for human health from the coal fuel cycle as a whole, including extraction and transportation of coal and producing electricity from coal [3,7]. The same types of coal (brown and hard) are considered as above. Risk estimates are given in the table for two types of coal extraction: underground mining and strip mining. Risk estimates for coal mouth mining are assigned to hard coal because this type of coal is typically extracted from underground mines. Accordingly, risk estimates for coal strip mining are assigned to brown coal because this type of coal is strip-mined. As for the risk from producing electricity, lower estimates are given for less-populated region, and higher estimates are used for highly-populated regions.

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Stages of fuel cycle		Estimate			
		Brown coal	Hard coal		
Extraction		0.24-0.33	5.5-5.8		
Transportation		0.37-0.5	56		
Electricity	SO_2	1.2-17.4	2.0-29.0		
production	NO _x	0.1-3.0	0.4-8.3		
	Particulates	0.28-4.3	0.36-5.4		

Table 4: Risks from coal fuel cycle, mortality/GW-year

Risk estimates for human health from the nuclear fuel cycle are presented in Table 5 [7]. These estimates were based on the assumption of normal (non-accidental) operation of nuclear facilities at all stages of the nuclear fuel cycle.

Table 6 contains estimates for the nuclear scenario of total emissions that result from electricity generation for export by coal-fired RFE power plants (both TPPs and co-generation). The figures showing the total amount of oxides and particulates were obtained by multiplying export electricity generation from RFE coal-fired plants (2.55 TWh in total, see Table 1) and corresponding figures from Table 3. The total amount of Carbon emissions were estimated by multiplying the content of Carbon in coal (Table 3) and the amount of coal required for export electricity generation by RFE TPPs and co-generation (see Table 2).

According to Ognev [8], harmful emissions from fossil fuel-fired power plants of RFE EPS amounted to 265 thousand tons (sum of particulate, nitrogen oxides, and sulfur oxides) in the year 2000. CO_2 emissions reached 24 Mln. Tons (measured as carbon dioxide) in the same year. Thus, emissions from electricity generation produced for export are equal to 6.5-11.5% and 8.5% of total current RFE EPS emissions of oxides & particulates and Carbon, respectively.

Stages of fuel cycle		Estimate		
Extraction	Strip mining	0.05-0.11		
	Mouth mining	0.3-1.04		
Fuel production		0.04-0.7		
Transportation		0.003-0.027		
Electricity production		0.334-0.51		
Decommissioning		0.0016		
Storage		0.0015-0.0215		
Total		0.43-1.37 (strip-mining extraction)		
		0.69-2.3 (mouth-mining extraction)		

 Table 5: Risks from the nuclear fuel cycle, mortality/GW-year

Pollutant	Amo	ount
SO ₂	6.6-8.9	
NO _x	3.8-12.75	} 17.3-30.35
Particulates	6.9-8.7	
Carbon	640	

As can be seen from Table 1, about half of the electricity generated for export is produced by RFE TPPs, with another half being produced by co-generation. This brings about a similar allocation of coal consumption (see Table 2) and, therefore emissions between RFE TPPs and co-generation. This division is important for assessment of risk from the coal fuel cycle. Co-generation, though producing half of the emissions, is located within or nearby cities, and this proximity brings about higher risk for people health. TPPs, also producing half of the net emissions, are usually located far from cities, and this makes risk to human health from their operation lower. Thus, risks from TPPs emissions are estimated to be at the low end of values from the ranges given in Table 4 ("Electricity production" row). Accordingly, risks from co-generation emissions are estimated to be at the high end of the values from the given ranges. Therefore, taking into consideration these results, risks from export electricity generation by TPPs and co-generation in total are estimated to be approximately at the level shown as average values from the ranges given in Table 4, "Electricity production" row. Estimates of specific risks from the coal fuel cycle for the nuclear scenario are provided in Table 7.

The estimates in Table 7, however, are measured in units of "mortality/GW-year". To apply these estimates conveniently to further calculations, these units should be converted to units of "mortality/TWh". To make this conversion, it is necessary to keep in mind that 1 GW-year is equal to 8.76 TWh. So, to convert a value measured in "GW-year" units to a value measured in "TWh" units, it is necessary to divide the former by 8.76. Risk estimates measured in "mortality/TWh" unit are given in Table 7.

Estimates of the total risk from the coal fuel cycle in the nuclear scenario are obtained by multiplying the amount of electricity generated for export by RFE coal-fired power plants (2.55 TWh/year, see Table 1) and applying corresponding estimates of risk measured in "mortality/TWh" units. The resulting estimates are also presented in Table 7.

Туре	Estimate
Specific risk of coal fuel cycle,	13.75-29.09
mortality/GW-year	
Specific risk of coal fuel cycle,	1.57-3.32
mortality/TWh	
Total risk of coal fuel cycle, mortality/year	4.0-8.47
Specific risk of nuclear fuel cycle,	0.43-2.3
mortality/GW-year	
Specific risk of nuclear fuel cycle,	0.049-0.262
mortality/TWh	
Total risk of nuclear fuel cycle,	0.29-1.57
mortality/year	
Total risk for scenario, mortality/year	4.29-10.04

Table 7: Estimates of risk caused by electricity export at nuclear scenario

Risk estimates for the nuclear fuel cycle were compiled by multiplying the amount of electricity generated by RFE nuclear capacity for export (6.0 TWh/year, see Table 1) by corresponding estimates of risk from nuclear fuel cycle converted to being units of mortality (deaths)/TWh (see Table 7). Estimates of total risk for the nuclear scenario of electricity exports are preliminarily calculated to be from 4 to 10 mortal cases per year. About 85-90% of these values, however, are brought about by the coal fuel cycle.

3.2 Nuclear scenario with conversion of cogeneration to gas

As is shown in the previous section of this paper, though the scenario for electricity export is named "nuclear", coal-fired power plants contribute greatly to environmental emissions and risks. It has been proposed to convert the fuel supply for co-generation from coal to gas [6]. This change substantially reduces emissions and, to an even greater extent, the human health risks of the scenario. This reduction is why a nuclear scenario with conversion of co-generation from coal to gas was considered.

Tables 8 and 9 provide estimates of specific emissions from gas-fired power plants [3,5] and of risks from gas fuel cycles [7], respectively. Conventional steam turbine units are considered for gas-fired plants. Low-range estimates of risk from electricity production (Table 9) present risks for less-populated regions. High-range estimates present risks from electricity production for highly-populated regions.

Pollutant	Amount
NO _x , g/kWh	2.2-3.9
Carbon, tons of Carbon/tce	0.41

Table 8: Specific emissions from gas-fired TPP	Table 8:	Specific	emissions	from	gas-fired	TPPs
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Fable 9:	Risks	from g	gas fuel	cycle,	mortalit	y/GW-year
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Stages of fuel cycle	Estimate
Extraction, processing, transportation	0.16-0.17
Electricity production (NO _x)	0.3-6.5

Estimates of emissions from gas-fired co-generation plants are presented in Table 10. NO_x emissions were calculated in the same way as was described above for the coal fuel cycle. As for carbon emissions, some explanation is required. Gas-fired power generating equipment has usually somewhat higher thermal efficiency than coal-fired power plants. As such, the level of fuel consumption given in Table 3 for cogeneration plants (0.5 Mln. tce/year of coal) should be recalculated for the case of gas-fueled plants. It was assumed that the specific fuel consumption of gas-fired power plants is equal to 0.31 kgce/kWh. Given this assumption, generation of the same amount of electricity (1.3 TWh/year, see Table 1) by gas-fired plants requires 0.44 Mln. tce/year. Estimates of Carbon emission from gas-fired plants based on this amount of fuel consumption are given in Table 10.

Estimates of emissions from coal-fired TPPs for the scenario considered are also presented in Table 10, and were calculated in the same way as those obtained in the previous section of this paper. As can be seen from the Table, the total amount of oxide and particulate emissions for the scenario are found in the range 11-20 thousand tons per year. Total Carbon emissions are close to half a million tons per year.

Pollutant		Amount	
Gas-fired	NO _x	2.9-5.1	
plants	Carbon	180	
Coal-fired	SO ₂	3.25-4.4	
plants	NO _x	1.9-6.25	
	Particulates	3.4-4.25	
	Carbon	300	
Total	SO_2	3.25-4.4	
	NO _x	4.8-11.35	} 11.45-20.0
	Particulates	3.4-4.25	
	Carbon	480	

Table 10: Emissions caused by electricity export at nuclear scenario with conversion of co-generation to gas, 10³ tons/year

Risk estimates over the full gas fuel cycle for the scenario are presented in Table 11. As long as gas-fired co-generation is assumed to be located within cities, maximal values of the range of estimates of risk from electricity production, which characterize risks for highly-populated areas (see Table 9), are used for calculations.

As for the coal fuel cycle, the lower values of estimates of risk of electricity production (see Table 4) are used for this risk assessment, because coal TPPs are located in less-populated areas. Risk estimates for coal fuel cycle-related impacts, along with total risk estimates for the considered scenario, are shown in Table 11.

Risk estimates for the nuclear fuel cycle remain the same as those estimated for the previous scenario.

As can be seen from Table 11, the total risk estimate for the nuclear scenario with conversion of co-generation for gas range from 2-4 deaths/year being considerably lower than those obtained for previous scenario. Additional scenarios are also considered under conditions that RFE co-generation is gas fueled.

Туре	Estimate
Specific risk of gas fuel cycle, mortality/GW-	6.66-6.67
year	
Specific risk of gas fuel cycle,	0.76
mortality/TWh	
Total risk of gas fuel cycle, mortality/year	0.99
Specific risk of coal fuel cycle,	2.19-9.1
mortality/GW-year	
Specific risk of coal fuel cycle,	0.25-1.04
mortality/TWh	
Total risk of coal fuel cycle, mortality/year	0.31-1.3
Total risk of nuclear fuel cycle,	0.29-1.57
mortality/year	
Total risk for scenario, mortality/year	1.59-3.86

 Table 11: Estimates of risk caused by electricity export at nuclear scenario with conversion of co-generation to gas

3.3 Hydro scenario

In this scenario nuclear capacity is substituted for by hydroelectric capacity in the RFE. In terms of power system interconnection, this means that the 6 TWh/year produced by RFE nuclear capacity for export is substituted for by the sane amount of energy produced by RFE hydropower capacity An analysis of RFE prospective hydropower development is done by Ognev in [8]. According to this study, more than 1.5 GW of hydropower capacity with an annual output exceeding 6 TWh may be phased in by the year 2015 in the south regions of the RFE (see Table 12). The South Yakutia hydropower complex, with a total capacity of 5 GW and yearly generation of more than 23 TWh, could be phased in after 2015. Part of this electricity generation can be exported.

Region	Hydropower plant	Installed capacity,	Yearly generation,
		GW	TWh
South RFE	Nizhne-Bureysk	0.321	1.6
	Cascade of Nizhnezeysk	0.349	2.12
	HPPs		
	Urgalsk-1	0.6	1.8
	Dalnerechensk-1	0.25	0.54
	Subtotal	1.52	6.06
South Yakutia	South Yakutia	5.0	23.45
	hydropower complex		
Total		6.52	29.54

Table 12: Prospective hydropower development of South RFE and Yakutia

Since in the scenario considered hydropower generation substitutes for nuclear power generation with no additional emissions being produced, emissions of SO_2 , NO_x , particulates and Carbon remain the same as those for Nuclear scenario with conversion of co-generation

to gas. Since the nuclear fuel cycle is avoided in the Hydro scenario, risks for the scenario are reduced by the value of risks of nuclear fuel cycle. Thus, the total risks for the Hydro scenario are estimated to be 1.3-2.29 mortality/year. As noted earlier in this paper, this estimate does not include risks specifically related to hydropower development or operation.

3.4 Fossil fuel scenario

Under this scenario, nuclear capacity is not phased in and hydropower capacity development is slowed down in the RFE. Thermal power capacity is developed instead. As considered in [6], Urgalsk coal-fired TPPs with capacity of up to 2.25 GW and yearly electricity generation of nearly 14 TWh can be sited in the RFE EPS. In this case, the additional power generation required for export can be supplied with this TPP. So the 6 TWh/year generated for export by either nuclear or hydropower capacity in the scenarios considered earlier now is produced by coal-fired TPPs. This level of export generation requires 2.1 Mln. tce/year (6 TWh/year×0.35 kgce/kWh) of coal to be consumed by the TPP. This in turn brings about emissions of oxides and particulates at the estimated levels presented in Table 13. The total emissions for the scenario as a whole, ranging roughly from 50 to 90 10^3 tons/year, are also given in Table. 13 These values were calculated by addition of emissions from the export generation by coal-fired TPP mentioned above to emissions from the Hydro scenario.

Pollutant		Amount	
Coal-fired TPP	SO ₂	15.6-21.0	
additional	NO _x	9.0-30.0	
export	Particulates	16.2-20.4	
generation	Carbon	1400	
Total for	SO ₂	18.85-25.4	
scenario	NO _x	13.8-41.35	} 52.25-91.4
	Particulates	19.6-24.65	
	Carbon	1880	

Table 13: Emissions caused by electricity export at Fossil fuel scenario, 10³ tons/year

Table 14 shows estimated risks for 6 TWh/year coal-fired TPP export generation and risks in total for the scenario. Risks for additional coal-fired TPP generation were estimated in the same way as those for the Nuclear scenario with conversion of co-generation to gas. Total risks for the scenario were estimated as addition of the above risks with those for the Hydro scenario. Total risk ranges in the interval between 2.8 and 8.53 deaths/year.

Table 14: Estimates of risk caused by electricity export at Fossil fuel scenario, mortality/year

Туре	Estimate
Coal-fired TPP additional export generation	1.5-6.24
Total for scenario	2.8-8.53

3.5 *Comparative analysis of scenarios*

Table 15 summarizes the environmental impacts of scenarios of electricity export from the RFE. As is shown, the Nuclear scenario has the highest estimates of risk. The major contributor to this risk, however is not the nuclear fuel cycle, but risk related to operation of coal-fired co-generation facilities. Conversion of co-generation plants in the RFE from coal to gas reduces risks by more than 60 %. In addition, emissions of SO₂, NO_x and particulates decrease by about one third and Carbon emissions are reduced by one quarter. The Hydro scenario reduces risks by about 20-40 % in comparison with the Nuclear scenario with conversion of co-generation to gas, with emissions remaining the same. The Fossil fuel scenario, conversely, greatly increases emissions in comparison with the Nuclear scenario with conversion of co-generation to gas: the increase is about 360 % for SO₂, NO_x and particulates and 290 % for Carbon. Risks increase by about 80-120 % in comparison with the Nuclear scenario with conversion of co-generation to gas.

Scenario	Emissions, 10 ³ tons/year		Risks, mortality/year
	SO_2 , NO_x , particulates	Carbon	
Nuclear	17.3-30.35	640	4.29-10.04
Nuclear with	11.45-20.0	480	1.59-3.86
conversion of co-			
generation to gas			
Hydropower	11.45-20.0	480	1.3-2.29
Fossil fuel	52.25-91.4	1880	2.8-8.53

 Table 15: Environmental characteristics of scenarios of electricity export from RFE

As can be seen from the table above, the Nuclear scenario with conversion of cogeneration to gas and the Hydro scenario have the least emissions. The Hydropower scenario also shows an estimated level of risks lower than those of other scenarios.

It is necessary to emphasize, however, that only a few environmental issues were analyzed in this paper. In addition, the economic effectiveness of the scenarios was not taken into consideration.

4. Conclusions

1. Power system interconnection causes various environmental benefits and impacts. The former include: lessening environmental damage from construction and operation of power plants in countries importing electric power; and large non-fossil fuel power plants (hydraulic, tidal, nuclear) can be phased in and effectively and reliably operated within systems including power interconnections, where they can substitute for fossil fuel power plants and provide other benefits. The latter include: impacts from construction and operation of ISETs themselves and from power plants in electricity exporting countries; additional power generation in the power interconnection case due to losses for power transfer via ISETs, and additional environmental impacts caused by this additional generation.

2. The RFE EPS participates in the "RFE-DPRK-ROK power system interconnection as a net exporter. Thus, participation in the PSI causes additional environmental burdens for the RFE.

3. Consideration of environmental impacts in this paper was limited to SO_2 , NO_x , particulates and Carbon emissions from fossil fuel-burning power plants, and risks (hazard) for human health from fuel cycles. The input data for the assessment of emissions and risks from RFE power plants was assumed based on data available in publications for analogous plants in other areas of Russia.

4. Three scenarios of Russian Far East EPS development and electricity export from the RFE were considered: Nuclear, Hydro and Fossil fuel. In addition, the Nuclear scenario was considered under a condition where co-generation fuel supply is converted from coal to gas. The Hydro and Fossil fuel scenarios were considered under the same condition. Neither the Nuclear nor the Hydro scenarios are "pure" nuclear or hydro. In both scenarios other types of power plants also contribute to generation for electricity export, though nuclear or hydropower generation supplies the largest share of the exported electricity. Development of TPPs in the Fossil fuel scenario is also accompanied by some development of HPPs.

5. The Nuclear scenario with conversion of co-generation to gas and the Hydro scenario have the least emissions. The Hydro scenario also offers minimal risks—lower than the other scenarios. The Fossil fuel scenario shows the maximal emissions of SO_2 , NO_x and particulates among the scenarios tested, with emissions exceeding those of the Hydro scenario by 360%. Carbon emissions are also highest in the Fossil fuel scenario, exceeding those of the Hydro scenario by 290%. The Nuclear scenario has risk estimates exceeding by 230-340% those of the Hydro scenario. A major contributor to risks in the Nuclear scenario, however, are impacts related to operation of co-generation plants.

6. Several environmental issues were analyzed in this paper, but many more are applicable to interconnection scenarios. In addition, the economic effectiveness of the scenarios was not taken into consideration. The environmental impact/benefit estimates obtained need to be considered as preliminary only, and further verification and analysis of input data, of the estimation methodology and of the results of this work needs to be conducted.

5. References

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