**Environmental Aspects of Electricity Grid Interconnection in Northeast Asia**

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Environmental degradation is widespread in Northeast Asia, particularly atmospheric pollution. Enhanced electricity grid interconnections in Northeast Asia offer two distinct kinds of benefits: (a) the spatial separation of generating source and point of electricity use, and (b) the substitution of cleaner fuels for coal. The first of these factors offers real potential. In most of the region, the pollution sources, i.e., the power plants, are geographically co-located with the points of electricity use, i.e., the population centers. Thus, there is maximum exposure of populations to elevated ambient pollutant concentrations, and damage to human health results. Second, coal is the cheapest and most readily available fuel for electricity generation in the region, and its combustion leads to high emissions of airborne pollutants. If the electricity generation can occur in places where cleaner fuels are more plentiful (whether natural gas, hydroelectricity, nuclear, or other renewable energy sources), then additional benefits can accrue.

It is presumed that there are three general types of cross-border interconnections that are feasible: (A) from the Irkutsk/Lake Baikal region of Siberia through Mongolia to the Beijing area; (B) extensions from north-eastern China or Russia to the Democratic People's Republic of Korea (DPRK) and perhaps to the Republic of Korea (ROK) and Japan; and (C) from Far East Russia via Sakhalin Island to Hokkaido by submarine cable and thence to the rest of Japan (*1*). These possible pathways are illustrated in Figure 1.

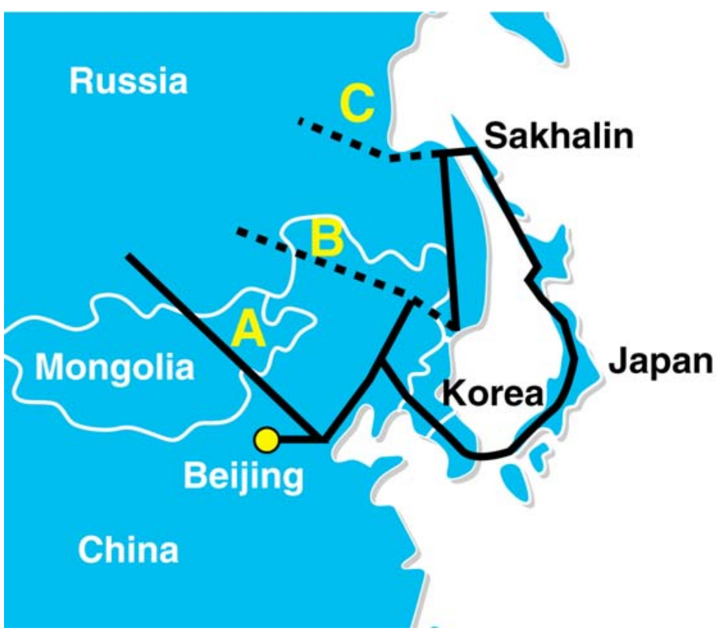


Figure 1 Potential electricity grid interconnections in Northeast Asia (adapted from [*1*])

Coal, natural gas, and hydropower are abundant in East Siberia and the Russian Far East. At present there are 22 GW of installed hydroelectric capacity and 8 GW of coal thermal capacity in the region. This part of Russia is expected to undergo rapid economic growth in the future, due to its largely unexploited minerals and energy potential. Thus, there are an additional 12 GW of capacity presently under construction (5 GW of hydro and 6 GW of coal thermal) with another 15 GW planned, including 2 GW of nuclear power. Construction of most of this generating capacity is likely to go ahead even without electricity exports, because of local demand. However, at present, electricity supply exceeds demand, so Russia wishes to generate ancillary revenues from the sale of excess electricity—thereby acquiring capital to build further plants in the future. Later in this paper we discuss specific projects. Suffice it to say at this point that Russia is seeking to develop cooperative projects with China, the DPRK, the ROK, and Japan that would allow the construction of transmission lines and sale of electricity from Russian generating plants. There are undoubtedly physical, economic, and political obstacles to be overcome before these projects can be realized. However, the focus of this paper is on the environmental aspects.

There has been only very limited prior experience of cross-border power transfers in Northeast Asia (*1*). Russia and China have had some effective power flows at local level, but no bulk power transfers. Mongolia, on the other hand, has received power from Siberia for many years. There are interconnections from Chita to eastern Mongolia and from Krasnoyarskaya to western Mongolia. However, the scale of power transfers has always been small (0.1 to 0.3 GWh), and the capacities of the lines are insufficient for greatly increased transfers. Additional capacity that would supply Erdenet and Ulan Bator is envisioned if Mongolian electricity demand should increase significantly. There are jointly constructed hydroelectric plants on the border between China and the DPRK but no physical linkages between the power systems. Thus, any initiative to create a large-scale bulk power transfer between countries in Northeast Asia would be the first of a kind.

There is no doubt that electricity demand will increase dramatically in the future throughout Northeast Asia and that much of that demand will be supplied by coal-fired power plants. Table 1 presents information about current and projected future fossil-fuel energy demand for power in the region from the RAINS-Asia computer model under mid-range energy forecasts (*2,3*). For this work, we focus on the Northeast Plains region of China, which we define to include the provinces of Heilongjiang, Jilin, Liaoning, and Inner Mongolia, together with the municipalities of Beijing and Tianjin.

The Northeast Plains region of China, despite its large existing generating capacity, is still power-poor. *Per capita* installed generating capacity is only about 0.25 kW (compared with 1.7 kW for OECD countries). Further economic development in the region is unavoidable. Thus, the North China Power Group, for example, has more than 10 GW of new, large power plants planned or under construction at ten sites (*4*). With limited hydroelectric resources in the region, no nuclear experience, and no plans to utilize scarce, expensive oil and gas resources, all of these plants will be coal-fired. This will further degrade the physical and atmospheric environment.

Table 1
Developments in power sector fossil-fuel energy demand (PJ)

| Region | Year 2000 | | | Year 2020 | | |
|---|---|---|---|---|---|---|
| | coal | oil | gas | coal | oil | gas |
| NE Plains/PRC | 1505 | 189 | 18 | 2347 | 110 | 140 |
| DPRK | 199 | 0 | 0 | 480 | 0 | 0 |
| ROK | 752 | 362 | 230 | 1237 | 339 | 730 |
| Japan | 1784 | 1703 | 1757 | 3161 | 1271 | 1281 |
| Total | 4240 | 2254 | 2005 | 7225 | 1720 | 2151 |
| Growth (%) | | | | 70.4 | -23.7 | 7.3 |

Source: (*2,3*)

Table 1 shows that coal use for power generation in the region is projected to grow by a massive 70% over the twenty-year period, 2000-2020. Oil use for power generation is projected to fall by 24%, as Japan seeks to reduce its dependence on imported oil. Gas use may grow slightly in the region (by 7%), if Northeast China can obtain sufficient supplies from western provinces. The Republic of Korea also plans to add gas-fired capacity. Nevertheless, with oil largely reserved for transportation use and natural gas preferred for residential use, coal will continue to shoulder the major burden for power generation. (Note that contributions of hydro, nuclear, and renewables are also part of these projections, but not reported here.) If some of this growth in coal-fired capacity can be avoided by importing clean electricity, then the atmospheric environment will undoubtedly benefit.

The energy resources of eastern Russia are very large, in contrast to the other countries. Hydroelectric resources are particularly plentiful. The technical potential of East Siberia is about 660 TWh $yr^{-1}$, of which 14% is utilized, while the technical potential of Far East Russia is 680 TWh $yr^{-1}$, of which only 2% is utilized (*5*). In contrast, the hydroelectric resources of north China are about 20 TWh $yr^{-1}$. Natural gas reserves are also huge in eastern Russia, estimated at 2 Tcm, of which almost nothing is presently exploited (*5*). Natural-gas combined-cycle power plants are definitely an option in the locations of gas fields. Oil reserves are large, but there are no plans to develop oil-fired power plants. Russia is also considering exploiting tidal power, with more than 80 GW of capacity under consideration for the future. Though Russia does hold sizeable coal deposits and presently uses coal for power generation in the region, it is likely that the electricity supplied to the rest of Northeast Asia would not come from coal-fired plants.

The types of power plants and fuels that have been discussed in actual project plans are discussed later in this paper. On these premises, we can envision that environmental benefits could arise in a number of ways:

- reduced emissions of local air pollutants;
- reduced human exposure to ambient pollution, due to the separation of source and point of electricity use;
- potential reductions in long-range pollutant transport and regional problems like acid rain, ozone, etc.;
- potential reductions in greenhouse-gas emissions;
- reduced coal mining and coal transportation;
- opportunity to displace biofuel combustion in rural areas; and
- encouragement of harmonized environmental regulations.

Despite this optimistic view of the likely environmental benefits of increased grid interconnectivity, we can imagine several ways in which such projects could endanger both the atmospheric and non-atmospheric environments:

- increased combustion emissions at point of electricity generation;
- increased methane emissions from natural gas extraction, processing, and distribution, if gas plants are the source of the electricity;
- possible marine ecosystem damage from offshore gas extraction and undersea cables;
- possible human health and ecosystem effects from transmission lines; and
- the environmental effects associated with the alternative energy sources (nuclear, hydro, etc.).

Air quality benefits can be realized at three spatial scales: local (both urban and rural), regional, and global. In each case, the benefits can take several forms and be of varying magnitudes. Each of these scales will be discussed in general terms before an examination of individual projects will be undertaken. At that point, some of the actual benefits and dis-benefits can be quantified and compared with the present-day magnitude of atmospheric emissions in the affected regions.

## Local-Scale Issues

The cities of Northeast Asia (Japan largely excepted) all battle air quality problems because of the extensive use of coal to fuel economic development. Interconnection option A (in Figure 1) could supply electricity to Beijing and Tianjin and other industrial cities in the region, such as Shijiazhuang. It could also help to alleviate Mongolia's electricity deficiency along the way. By extending further to the west, it would be possible to connect some of the most polluted cities in northern China: Taiyuan, Lanzhou, and Yinchuan. Option B could supply electricity to the industrial Northeast Plains, where, again, are some of China's most polluted cities: Shenyang, Changchun, and Harbin. All these cities regularly figure at the top of the list of cities with an air quality index of Class III and IV. Pyongyang could be an additional beneficiary.

Ambient concentrations of sulfur dioxide, nitrogen oxides, and particulate matter would all be reduced in these cities. If the interconnection could stretch to the ROK, then the large industrialized area around Seoul would undoubtedly benefit, because rapid electricity demand growth is anticipated there with few attractive generation options. Option C in Figure 1 could ultimately assist Tokyo in maintaining acceptable ambient pollution levels, but generally it is in northern China and perhaps the DPRK that the local benefits are greatest.

Table 2 summarizes some recent ambient air-quality information for cities in Northeast China. These annual-average data have been aggregated by the World Bank from daily measurements taken in Chinese cities (*6*). Normally, the data are converted into an air pollution index, which is released to the public daily to communicate the state of current pollution levels. Table 2 only includes those cities in the Northeast Plains region, as defined above in connection with Table 1, and two cities further to the west, Taiyuan and Lanzhou.

Table 2
Annual average pollution concentrations in Chinese cities in 1995 (:g $m^{-3}$)

| City | $NO_x$ | $SO_2$ | TSP |
|---|---|---|---|
| Beijing | 122 | 90 | 377 |
| Changchun | 64 | 21 | 381 |
| Dalian | 100 | 61 | 185 |
| Harbin | 30 | 23 | 359 |
| Lanzhou | 104 | 102 | 732 |
| Shenyang | 73 | 99 | 374 |
| Shijiazhuang | 61 | 129 | 308 |
| Taiyuan | 55 | 211 | 568 |
| Tianjin | 50 | 82 | 306 |
| WHO Guidelines | 150 | 100-150 | 150-230 |

Source: (*6*)

Some general observations can be made from Table 2. First, ambient levels of $NO_x$ are typically lower than the WHO guideline value to protect human health, in this case 150 μg $m^{-3}$. This is because there are fewer vehicles than in the cities of most developed countries; however, $NO_x$ concentrations are the fastest growing of all species. Levels of $SO_2$ hover around the WHO guideline of 100-150 μg $m^{-3}$. Because these are annual average values, there are undoubtedly many days in a year when the $SO_2$ guidelines would be exceeded. This is particularly true for the heavily industrialized, coal-burning cities like Taiyuan. Finally, concentrations of total suspended particles (TSP) are generally exceeded much of the time. This is a combination of coal smoke and vehicle exhaust emissions—often compounded in the winter and spring months by windblown dust from the deserts and marginal cultivated lands of the western provinces. Coal-fired power plants are major contributors to the high levels of all three of these species. Beijing has recently banned the use of coal in the city.

Existing power plants are usually co-located with urban centers in Northeast Asia. For ease of labor, transport, and electricity supply, there is no effort to distance plants from population centers. These plants are typically large, coal-fired stations with only electrostatic precipitators for control of particulate matter (and no $SO_2$ or $NO_x$ controls). They contribute to the high ambient levels of pollution in northern Chinese cities, which impair human health, largely through inhalable particulate matter (PM) (*7*). This is largely a mixture of primary particles and secondary sulfate (though ambient $SO_2$ itself is a health danger in some northeastern cities). It is generally accepted that there will not be appreciable alteration in the practices of Chinese power generation in the coming decade.

The possible exception to this concerns China's recent introduction of the "Two-Control-Zone" policy, an attempt to limit $SO_2$ emissions in order to protect against excessive sulfur deposition and acid rain (*8*). How effective this policy will be remains to be seen. Thus far, China has not had to implement tough controls on power plants, such as installation of flue-gas desulfurization (FGD) systems. The trend in $SO_2$ emissions has turned downward since 1996, and year 2000 targets were met without extra effort (*9*). In the coming decade, however, China might have to consider the expensive FGD option for new and some existing plants, in order to meet future emission targets. For this study, however, we assume that the default option for China is uncontrolled coal-fired power generation.

The remarkable transformation that has occurred in China since 1995 has had implications not only for environmental emissions, but also for power-sector trends and fuel-use trends. Among these trends (*10*) are the following:

- the economic recession of 1997-98 that swept through East and Southeast Asia;
- reform of industry and power, leading to a reduction in coal use;
- a structural shift away from heavy industry toward high-tech industries and services;
- improvements in energy efficiency and fuel quality;
- the closure of many small, inefficient, high-sulfur coal mines, reducing the over-supply of coal;
- a slowdown in electricity demand, due to higher electricity prices;
- the opening up of power and industrial markets; and
- residential fuel switching from coal to electricity and gas in (the larger) cities.

In addition to recent declines in nationwide emissions of $SO_2$ and $NO_x$ in China, the suppression of electricity demand through higher prices, coupled with a very fast pace of power-plant construction, has caused electricity supply to (perhaps temporarily) catch up with demand. This means that the imperative to find more generating capacity has been tempered. Thus, China today is less enthusiastic about imports of Russian-generated electricity than perhaps it was some five or ten years ago, when electricity shortfalls were widespread throughout China. In addition, China's strides to integrate its own electricity network have made it less vulnerable to electricity shortages. Thus—energy security issues aside—China cannot be expected to view favorably any costly investments to support transmission from beyond its own borders in the near future. Nevertheless, the environmental benefits of removing large coal-fired facilities from the vicinity of heavily populated areas cannot be overstated. This is undoubtedly one of the major causes of urban health damage in Chinese cities today.

## Regional-Scale Issues

Local-scale issues remain perhaps the most important aspects of air pollution in Northeast Asia, because they are most directly linked with damage to human health. However, there are a number of regional issues that are important over wider geographical scales. And, indeed, many of the local problems ultimately become regional problems, as the pollution disperses through time and space and undergoes chemical reactions and physical transformations. The regional air pollution issues are many:

- long-range transport from Northern China to the Korean peninsula and on to Japan and North America;
- regional visibility impairment and reduced insolation—compounded by dust from western deserts;
- acid rain, sulfur deposition, nitrogen deposition (with $NH_3$ involvement from fertilizer use), and eutrophication of surface waters;
- regional ozone formation, caused by organics + $NO_x$ with the involvement of CO and $CH_4$; and
- trace elements from coal combustion, particularly Hg.

The issue of acid rain and sulfur deposition has received much attention in Northeast Asia (*11-13*). For many years, coal-fired power plants in northern and eastern China have been held responsible for a proportion of sulfur and acidity that is ultimately received in the Korean peninsula and Japan. The magnitude of this transported pollution is the subject of lively dispute between China and its eastern neighbors. Sulfur dioxide emissions and sulfur deposition have received the most attention. Though the regional sulfur source-receptor relationships for Northeast Asia are in dispute for political reasons, certain aspects of the problem are clear. The Northeast Plains of China are strongly linked to sulfur deposition in the ROK, the DPRK, and Japan. According to the RAINS-Asia model, sources in the Northeast Plains are responsible for about 17% of sulfur deposition in the DPRK and 22% of sulfur deposition in Japan (*11*). In the ROK, the contribution is only 9% because local emissions are considerably higher there. From the point of view of alleviating long-range transport of pollution, it is clearly in this region of China that the greatest benefit of emission reductions would occur. Of course, China itself is the recipient of the majority of the sulfur, nitrogen, and acid deposition from its own sources. Studies of acid deposition in China show a gradually expanding range of elevated sulfur deposition amounts and rainfall pH in northern China (*12*). The acidity of rainfall is somewhat neutralized by the alkalinity of the windblown mineral dust from western China (*13*).

Table 3 illustrates some of the features of the sulfur source-receptor relationship in Northeast Asia in very simplified form (*11*). These values are taken from the RAINS-Asia model. This table shows that Shenyang receives 66% of its deposited sulfur from the surrounding Northeast Plains region. Similarly, Pyongyang receives 17% from NEP, 29% from sources in its own country, and 37% from the ROK. Tables like this one are useful for determining the potential benefit for distant regions of cuts in pollutant emissions in source regions. In percentage terms, greater benefit occurs when local emissions are small, like in Pyongyang; Seoul, on the other hand, has such large local emissions that reductions in emissions at distant locations have a less noticeable effect.

Table 3
Simplified sulfur source-receptor relationships for Northeast Asia

| Receptor/Source | NEP | Jiangsu | Japan | DPRK | ROK |
|---|---|---|---|---|---|
| Shenyang, PRC | 66 | 1 | 0 | 1 | 1 |
| Beijing, PRC | 0 | 1 | 0 | 0 | 0 |
| Tokyo, Japan | 2 | 2 | 78 | 1 | 9 |
| Pyongyang, DPRK | 17 | 3 | 0 | 29 | 37 |
| Seoul, ROK | 4 | 3 | 0 | 2 | 84 |

Source: adapted from (*11*)

Whatever the precise magnitude of these relationships, it is undeniably true that the location of coal-fired power plants in Northeast China makes them conducive to pollution transport toward the east. This is especially true during winter and spring when dominant high-pressure systems over Mongolia tend to sweep accumulated pollution off the landmass into the eastern oceans. Figure 2 illustrates the overall burden of sulfur deposition over Asia, as projected for the year 2020 by the RAINS-Asia model. Without further control measures, it is forecast that some areas of Asia could receive sulfur deposition at levels observed in eastern Europe during the 1960s, which caused severe ecosystem damage. Some of the greatest problems are projected to be in northeastern China and in the ROK—again, in areas where electricity grid interconnections could alleviate the problem by reducing $SO_2$ emissions from coal-fired power plants.

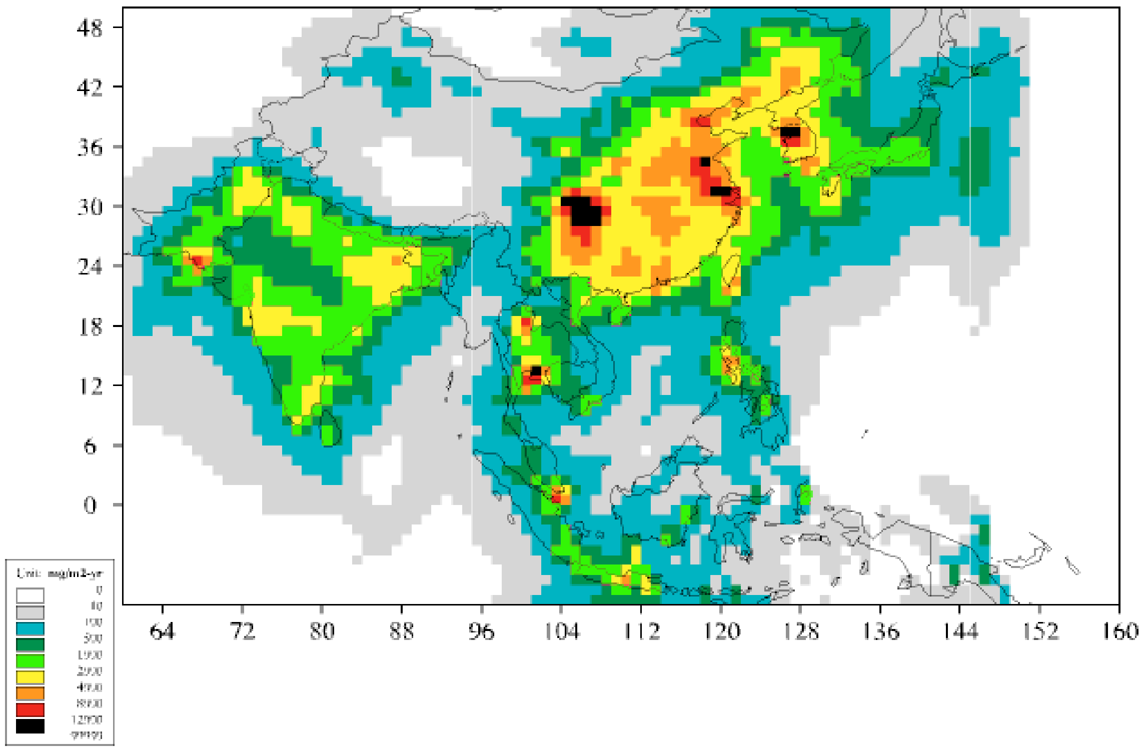


Figure 2 Projected sulfur deposition in Asia in 2020 (from [11])

Throughout northern China and the DPRK the ability to increase rural electrification would greatly benefit air pollution and human health. Coal and biofuels (wood, agricultural residues, and dried animal waste—in the west) are all burned in domestic stoves for cooking and, in the winter, heating (*14*). These combustors are notoriously inefficient. They generate large quantities of the products of incomplete combustion: carbon monoxide, methane, volatile organic compounds, and fine carbonaceous particles (*15*). These emissions are a threat at all spatial scales: from inhalation by women and children in kitchens, through the regional problems of reduced visibility and insolation, to the global warming potentials of the direct greenhouse gases, methane and black carbon (*16,17*). The gaseous species are also indirect greenhouse gases in that they participate in the formation of regional tropospheric ozone.

All these aspects of rural energy use in Asia are currently receiving great attention. So the import and distribution of additional electricity throughout these rural areas would bring with them a variety of largely unappreciated benefits. Many of the potential pathways of transmission lines from Russia to cities in the south would pass through relatively poor and underdeveloped regions (including Mongolia, the northern provinces of China, and the DPRK), where the ability to bleed off some electricity to rural communities could be of immense value. The U.S. rural electrification program of the 1930s was one of the great unifying features of the century, bringing with it communication, light, refrigeration, and mobility.

One of the most important of these regional pollutants is black carbon. This is composed of sub-micron, elemental carbon particles and is sometimes called soot (*18*). Large quantities of black carbon are released during low-temperature combustion in inefficient stoves, cookers, kilns, etc. This is typical practice in rural China. The black carbon can carry adsorbed carcinogenic hydrocarbons, causing health problems for women and children in kitchens. But the particles are small enough that they can remain aloft for days or weeks. Therefore, they can be transported over large distances and contribute to regional haze. Organic carbon compounds are similarly formed, in even larger amounts when biomass is burned.

Figure 3 shows the regional distribution of black carbon emissions in China (*18*). The distribution tends to follow the rural heartland of China. It is also heavy in Northeast China, particularly in coal-producing areas just to the west of Beijing. Rural electrification could gradually reduce these emissions and considerably clean up the atmosphere.

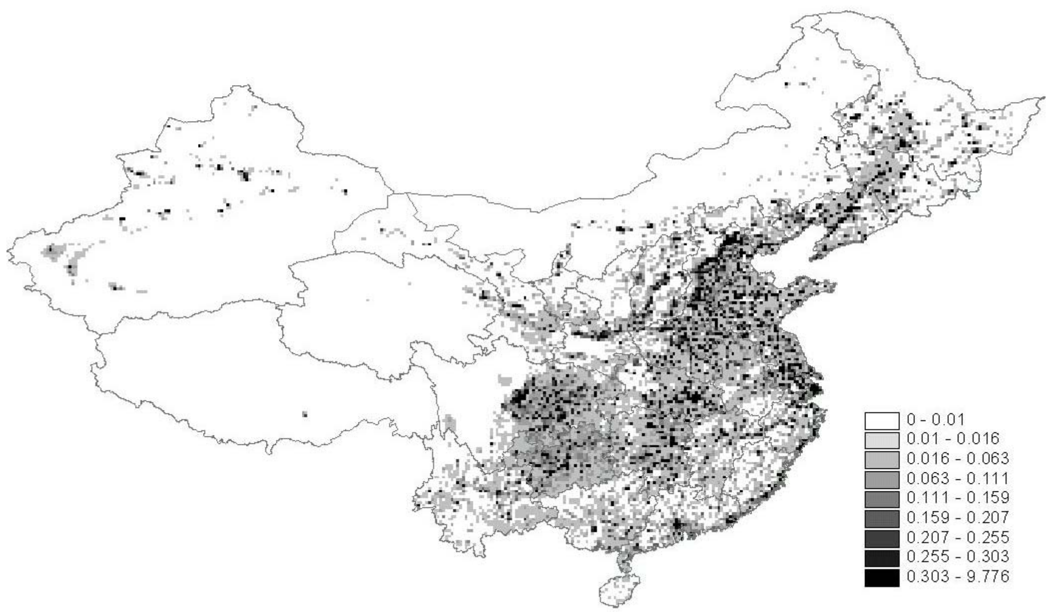


Figure 3 Distribution of black carbon emissions in China (*18*)

Another severe regional air pollution problem in Northeast Asia is ozone (*19*), caused by emissions of volatile organic compounds and $NO_x$. In the hot, humid, stagnant-air conditions of summertime China, photochemical reactions lead to the formation of ozone over large regional areas. Ozone damages human health through inhalation and also damages crops. It has been estimated that ozone levels in southern China are sufficiently high to cause serious crop damage (*20*). One problem is that we have relatively little good monitoring data to understand both the levels of ozone and the damage that is occurring in the field. The combined effect of fine particles and organic compounds in the air over China is to reduce the amount of radiation reaching the earth's surface (insolation). This has been shown to reduce crop yields by as much as 30% (*21*).

## Global-Scale Issues

On a global scale, any substitution of hydroelectricity, nuclear power, or other renewable energy source for coal will essentially eliminate emissions of carbon dioxide. Even substitution of natural gas for coal will reduce such emissions. This could be important to Japan, say under the interconnection option C. Japan is presently the only country in Northeast Asia required to reduce greenhouse-gas emissions under the Kyoto Protocol (by 6% from 1990 levels by 2008-2012). This is a real challenge for Japan, which already has a low energy-consuming economy that makes further reductions from domestic sources expensive. The advantages of imported electricity are thus clear. An energy "bridge" from Far East Russia through Sakhalin Island to Japan could supply a considerable amount of electricity from hydroelectric or nuclear power plants. Alternatively, natural-gas combined-cycle plants using the gas reserves of Sakhalin Island are possible. These options would help meet Japan's joint electricity and greenhouse-gas targets.

Japan has limited domestic options to meet the electricity growth that is forecasted to be needed to sustain economic growth. An additional 50 GW or so will be needed by 2010 (*1*). About half of this is planned to come from nuclear generation. However, recent nuclear plant accidents have heightened public concern about plant safety, and the goals of nuclear expansion must be seen as optimistic. With few unexploited domestic energy resources and difficulties with increasing the roles of photovoltaic and geothermal generation, it is difficult to see how the fossil-fuel option can be avoided—which would make the Kyoto target unreachable. Japan's $CO_2$ emissions from fossil-fuel consumption actually increased by 3% between 1995 and 1999 (*22*). All these factors make interties to Russian low-carbon generating plants quite sensible for Japan.

Other countries in the region are less concerned about this issue, because they are not signatories to the Kyoto Protocol. China, in particular, has reason for some self-satisfaction on the subject of greenhouse-gas emissions. The factors discussed earlier about the transformation of the energy-consuming economy (*10*) have led to a reduction in emissions of both $CO_2$ and $CH_4$ in China since 1996/7 (*23*). The decline in $CO_2$ emissions is primarily driven by the decline in coal consumption. This is shown in Figure 4. The declining use of biofuels and the increased growth of forests have contributed to this trend. Overall, $CO_2$ emissions have declined by about 7% since 1996.

The reduction in $CH_4$ emissions has been largely caused by an even greater reduction in coal mining (due to over-mining in previous years and stockpile accumulations) and hence in releases of coalbed methane. On the other hand, large increases in the number of livestock in China and in the amounts of municipal garbage generated and landfilled have counteracted the energy-related benefits. The net change has been a reduction of about 2% in $CH_4$ emissions in China since 1997. The implications of these trends are that China presently has little incentive to be concerned about reducing domestic emissions of greenhouse gases. It will require a return to economic vitality, renewed growth in fossil-fuel-fired energy production, and/or a new global compact on greenhouse-gas emission reductions to engage China on this issue.

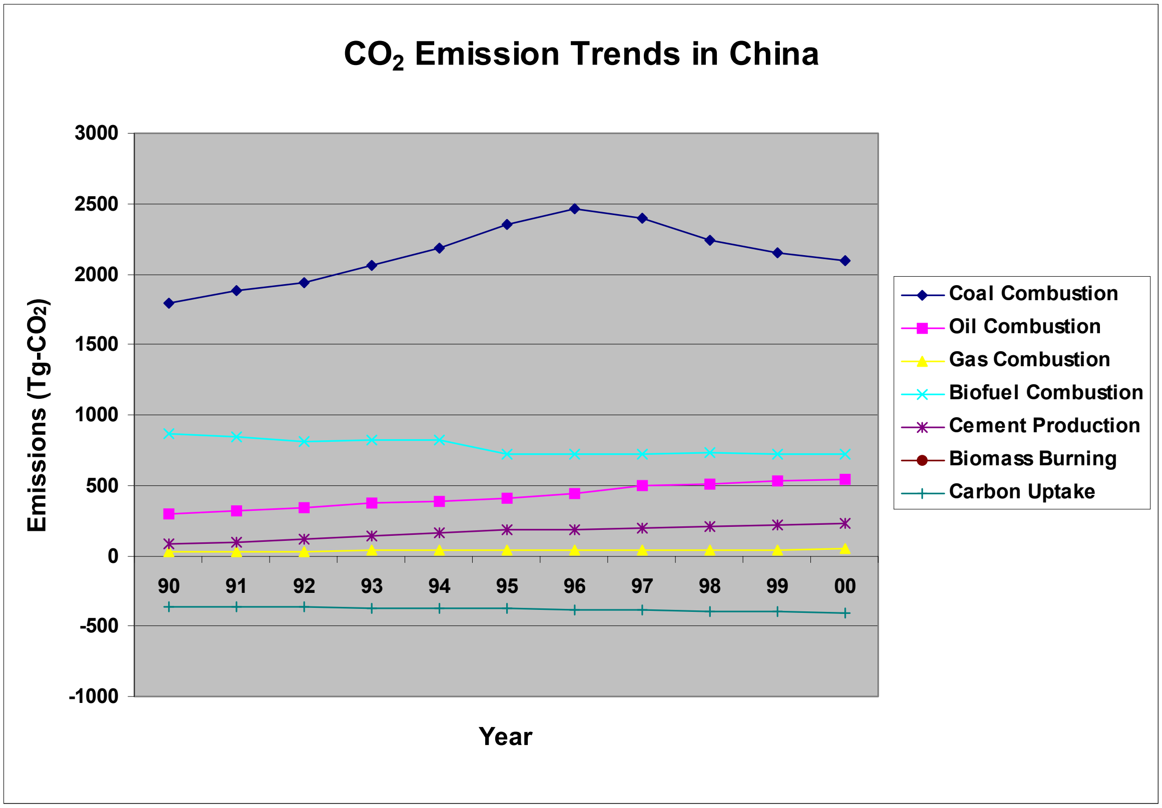


Figure 4 Decadal trends in $CO_2$ emissions in China by source type (*23*)

We can identify a number of issues that are potentially important at global scale for Northeast Asia:

- emissions of the gaseous greenhouse gases can be reduced ($CO_2$ mainly, but also $CH_4$ if coal production is curtailed);
- potential reductions in emissions of the greenhouse-gas black carbon can be achieved if rural fossil-fuel use and biofuel use can be reduced through electrification;
- the net emission reduction will depend on the technology and fuel used to generate the electricity at the source;

- net emissions of $CH_4$ could increase if natural-gas combustion is the source of the electricity (from extraction, processing, and distribution of the gas);

- there are energy and environmental policy issues specifically related to compliance with the Kyoto Protocol; and

- recent greenhouse-gas emission reductions in China have broad implications for national, regional, and global policy-making.

Overall, the avoidance of $CO_2$ emissions from coal-fired power plants is likely to generate a net reduction in greenhouse-gas emissions. Determination of the net effects on climate requires a full accounting of changes in emissions of all greenhouse gases. This calculation should include, at minimum, $CO_2$, $CH_4$, black carbon, and sulfate aerosol (which has a negative radiative forcing). In other work we have shown that the net effect of emission reductions in China could be an *increase* in global warming (*23, 24*), because the effect of the reduction in sulfate aerosol (a cooling substance) is larger than the combined effects of the reductions in the three warming substances. This ironic consequence for climate should, however, not detract from the other benefits of these emission reductions.

## Proposed Projects

A number of possible projects have been identified for supplying electricity from Russia to the other countries of Northeast Asia. Table 4 identifies the main prospects (*25*). Some of these, especially the two options feasible before 2015, have already undergone extensive pre-planning; some of the others are still speculative. Six projects are identified in Table 4. This is not to say that other projects might not come to the forefront in the next two decades—only that we do not know of them at present. Of the potential options, three would utilize hydroelectric resources, two would use nuclear power, and one would use natural-gas combined-cycle (NGCC) technology. Because NGCC plants are relatively quick and easy to construct, it is likely that they could offer greater potential than indicated here, once a mature gas industry is developed in Far East Russia. The two near-term options (before 2015) are envisioned to supply two Chinese cities, Beijing and Harbin. Thereafter, more ambitious options to supply the DPRK, the ROK, and Japan have been conceived.

Figure 5 illustrates the locations of the sources and the points of end use, as well as the potential routes of transmission lines. Note that the first option (No. 1 in Figure 5) would also pass through Ulan Bator, the capital of Mongolia, and offer the potential of supplying electricity to that city. Option 1 might actually end at Tangshan City, 150 km northeast of Beijing, and from there link to the capital. Note also that Option 3 in Figure 5 sends electricity directly from Russia to the DPRK, without having to cross China's borders. Options 5 and 6 are not included in Figure 5, because their transmission routes have not yet been determined. As indicated earlier, we do not pass judgment on the physical, political, or economic feasibility of these transmission options.

Table 4
Prospective electricity ties from East Russia to other Northeast Asian countries

| Generating Site/ Point of End Use | Fuel | Time Frame (yr) | Length (km) | Capacity (GW) | Electricity (TWh $yr^{-1}$) |
|---|---|---|---|---|---|
| 1 Bratsk/Beijing | hydro | before 2015 | 2600 | 3 | 18 |
| 2 Bureya/Harbin | hydro | before 2015 | 700 | 1 | 3 |
| 3 Primorye/DPRK<br>Primorye/ROK | nuclear | 2015-2025 | 700<br>1100 | 4/8 | 8.5 |
| 4 Sakhalin/Japan | NGCC | 2015-2025 | 470 | 4 | 23 |
| 5 RFE/PRC, ROK | nuclear | beyond 2025 | 2300 | 2.5 | 18 |
| 6 Uchursk/PRC, ROK | hydro | beyond 2025 | 3500 | 3.5 | 17 |

Source: (*25*)

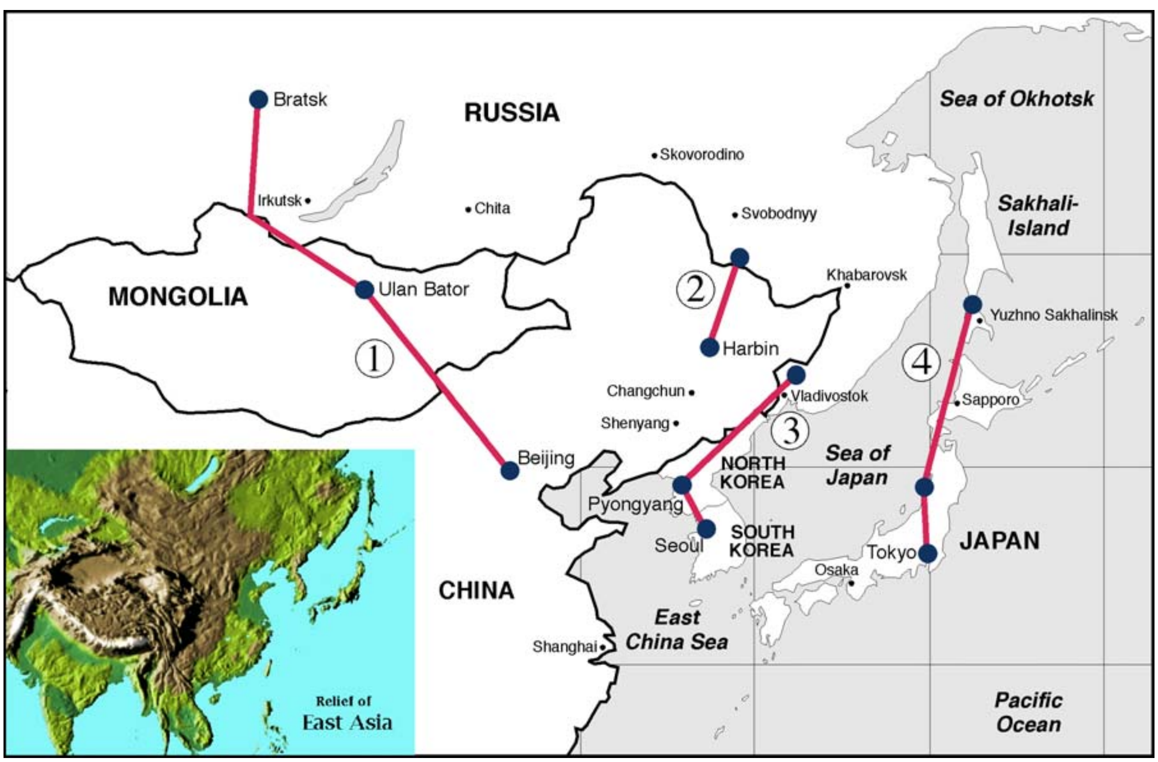


Figure 5 Routes of proposed interconnections in Northeast Asia (adapted from [*25*])

For each project the amounts of electricity available for transmission to neighboring countries are identified in the final column of Table 4. The total amounts are thus: 21 TWh (before 2015), 55.5 TWh (before 2025), and 90.5 TWh (beyond 2025). These quantities are subject to some uncertainty, of course, and other examinations of this potential generate slightly different estimates. It is instructive to compare these amounts with current generation in the Northeast Plains region of China. In 1999, the six provinces and municipalities of Beijing, Heilongjiang, Inner Mongolia, Jilin, Liaoning, and Tianjin generated 203 TWh of electricity. (This is 16% of the total electricity generated in China in 1999, 1239 TWh.) Therefore, in the timeframe before 2015, the amount of electricity that could be provided to the region is 10% of the amount of electricity presently (in 1999) being generated. And, of course, because of the fast-growing rate of electricity generation, this is a progressively smaller proportion as time goes on.

It can be concluded that the total amount of electricity available would not supply a large portion of Northeast China's electricity needs. However, it could provide all of Beijing's present-day needs (Option 1), with possibly some additional power for other Chinese communities (or Ulan Bator). Although we do not have an estimate of Harbin's electricity needs, it is probable that Option 2 would fulfill most of them in the near term. So the air pollution problems of a few Chinese cities could be greatly alleviated by these interties.

It is possible to further examine the environmental impacts of these actions by comparing the emission rates of several air pollutants from alternatively fueled power plants. Table 5 presents such a comparison. This table shows the emission rates of five species from typical (Chinese) coal-fired, oil-fired, and gas-fired power plants. We present two options for $SO_2$: with and without FGD systems. As indicated earlier, there are few FGD systems routinely employed on coal-fired power plants in China today, but the time may come—perhaps within the next decade—when this might be necessary in order to achieve the goals of the "Two-Control-Zone" policy (*8*).

Table 5 shows that coal-fired power plants are a major source of $SO_2$ (without FGD), $NO_x$, and $CO_2$. Total particulates are not presented here, only black carbon emissions. In general, power plants in China are not a big source of particles, because they tend to employ relatively efficient control systems like electrostatic precipitators. Oil-fired power plants, which are not used in China, generally have lower $SO_2$ and $CO_2$ emission rates than coal-fired plants. Gas-fired power plants have very low $SO_2$ emissions and somewhat lower $NO_x$ and $CO_2$ emission rates. Table 5 shows two other source types to make an additional point. Emission rates for the residential use of coal and biofuels are included in the last two rows. As discussed before, such fuels are widely used in rural areas of Northeast Asia to provide residential cooking and heating services. In these stoves and cookers, combustion is poor. Only about 85-90% of the carbon is fully oxidized to $CO_2$. The remainder is converted to CO, $CH_4$, higher hydrocarbons, and particles (including BC and OC). Table 5 reveals the much higher emission rates of CO and BC for residential coal and biofuel combustion than from power generation. These compounds all play roles in local health damage, regional particle and photooxidant problems, and climate change. This is why we emphasize the need to consider not only the replacement of coal-fired generating capacity in cities with clean electricity, but also the displacement of traditional rural fuels by dispersed electrification in the countryside.

Table 5
Typical emission factors (Gg $PJ^{-1}$) from power generation

| Fuel | $SO_2$ | $SO_2$* | $NO_x$ | CO | BC** | $CO_2$ |
|---|---|---|---|---|---|---|
| coal | 0.61 | 0.06 | 0.30 | 0.02 | 0.00001 | 96 |
| oil | 0.26 | 0.07 | 0.20 | 0.02 | 0.008 | 77 |
| gas | 0.01 | 0.01 | 0.15 | 0.03 | 0 | 56 |
| [coal] | 0.51 | 0.07 | 0.08 | 3.5 | 0.18 | 96 |
| [biofuel] | 0.06 | 0.06 | 0.05 | 5.1 | 0.07 | 110 |

*with controls, such as FGD for coal, low-sulfur oil, briquettes, etc.
**black carbon, i.e., sub-micron elemental carbon
[…] = residential fuel use

Estimates of the potential for regional emission reductions show that the benefits would be modest. The 21 TWh of electricity available before 2015 would avert approximately 10 million tonnes of coal use in Northeast China and 200 Gg of $SO_2$ emissions. However, this represents only about 12% of the $SO_2$ emissions from power plants in the region and 6% of total $SO_2$ emissions in the region. This reminds us of the fact that much of the coal in China (about 50% in northeastern China) is used in the industrial sector. So, unless industrial electrification can be enhanced, there is a limit to the extent to which imported electricity can displace coal.

In the regional context, therefore, it is not likely that an appreciable reduction in deposited sulfur or nitrogen would be achieved. Nor would recipient countries like the DPRK and Japan notice a significant reduction in long-range transported pollution or acid rain. Similarly, the reduction in greenhouse-gas emissions like $CO_2$ would be rather small compared to the total emissions in the region. Nevertheless, substantial local benefits could be achieved in some cities, such as Beijing and Harbin in the examples shown. Shenyang and Pyongyang would also be ideal targets, if extensions to them could be added. The likelihood that other cities could benefit is limited by the relatively modest amounts of electricity available. Rural communities in northern China, Mongolia, and the DPRK would benefit from reduced particulate levels, in addition to reduced $SO_2$, $NO_x$, CO, and other gases, if a contribution to rural electrification could be achieved.

## Conclusions

This analysis has shown that increased electricity interconnections in Northeast Asia offer the potential to improve local, regional, and global air quality by removing the point of electricity generation away from populated areas. In this way, exposure of urban populations to elevated levels of health-damaging air pollutants would be reduced wherever coal-fired generating stations are avoided. In addition, by substituting cleaner fuels (hydroelectricity, NGCC, and nuclear power) for the coal that is traditionally used to generate electricity throughout the region, overall emission levels would be reduced. Though the benefits are almost certainly positive overall, this analysis would be remiss without pointing out the potential negative consequences.

Balanced against the clear benefits at the point of electricity use, must be weighed the environmental pollution created at the point of fuel extraction and use for electricity generation. If natural gas is the fuel of choice, then the pollution generated at the point of gas extraction, including methane emissions, must be added to the leakages from processing and distribution, and the emissions—though low—from combustion. Nuclear power and hydroelectricity are associated with their own well-known sets of pollution and risks. In addition, undersea cables and offshore gas extraction pose an additional set of marine ecosystem threats under some options. But, overall, because of the sparsely populated nature of much of the Siberian resource regions, it is likely that the damage or risk of damage would be to natural ecosystems rather than to human health. The only additional possible threat to human health would be the still-controversial hazard from high-voltage transmission lines, due to magnetic fields or electrostatic induction. Prudent practice would suggest routing transmission lines away from populated areas.

We can conclude with the following summary observations:

- the local benefits to human health in several (perhaps 2-3) large cities in Northeast China could be significant in the near term (say, before 2015);
- local benefits may be possible in other cities in Northeast China, the DPRK, and the ROK in the longer term (say after 2015);
- both local and regional health benefits are possible from increasing rural electrification to displace traditional fuels in Northeast China, Mongolia, and the DPRK;
- the health benefits at the point of electricity use are likely to outweigh any health and ecosystem damages at the point of electricity generation;
- regional air-quality benefits (acid rain, sulfur deposition, ozone, etc.) are likely to be positive but small;
- global benefits are likely to be net positive (less so if natural gas is used for electricity generation) but very small; there is a risk that the combined effect on global climate

could be negative when all species are taken into account, due to the dominant effect of sulfate aerosol, but this awaits further scientific progress;

- Japan could achieve some benefit in meeting its Kyoto Protocol commitment;

- associated social benefits to parts of Northeast China, Mongolia, and the DPRK could be a by-product of greater access to electricity; but

- overall, the amount of electricity likely to be available is too small to have a really large effect on the environment of Northeast Asia.

The achievement of regional environmental benefits, such as the ones that would accrue from enhanced grid interconnections, pose both a challenge and an opportunity to present regulatory regimes. Though there are precedents for cross-border environmental compacts elsewhere in the world (such as the LRTAP (Long Rang Transboundary Air Pollution) Convention in Europe), in Asia the concept is in its infancy. Only recently has the Tripartite Environment Ministers Meeting (TEMM) among China, Japan, and the ROK taken the first steps to foster regional environmental cooperation and sustainable development. There is a long way to go before national policies can be harmonized and international agreements implemented in Asia. The harmonization of environmental regulations in the region is desirable, however. It can eliminate political instability arising from pollution transport across borders. But perhaps more importantly it removes any economic incentive to move industry away from regions of tight emission regulations into regions of lax emission regulations. This can be a real problem wherever highly developed economies abut very poor countries. Greater electricity ties across borders can be a positive force for respecting environmental integrity and harmonizing environmental policies and regulations.

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