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Energy 28 (2003) 789–807

ENERGY

www.elsevier.com/locate/energy

Environmental benefits of electricity grid interconnections in Northeast Asia

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Received 28 January 2002

Abstract

From an environmental perspective, electricity grid interconnections in Northeast Asia make sense. Cities in Northeast China, Mongolia, the Democratic People's Republic of Korea (DPRK), and the Republic of Korea (ROK) suffer from poor air quality due to the extensive use of coal-fired power generation. Rural communities suffer from a deficit of electricity, forcing reliance on coal and biofuels for cooking and heating in the home, which causes health-damaging indoor air pollution. Regional air pollution from acid rain and ozone is widespread. In addition, Japan is finding it hard to meet its commitment under the Kyoto Protocol. Yet, just across their borders in far eastern Russia are extensive, clean energy resources: hydroelectricity and natural gas, and (potentially) nuclear power and tidal power. It would be environmentally beneficial to generate electricity cleanly in far eastern Russia and transmit the electricity across the borders into China, Mongolia, the DPRK, the ROK, and Japan, thereby displacing coal-fired electricity generation. We estimate that currently planned projects could alleviate the problems of two to five Chinese cities, with the potential for much larger benefits in the future.

1. Introduction

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 major pollution sources, i.e. the power plants, are geographically co-located with the points of

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0360-5442/03/$ - see front matter © 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S0360-5442(03)00030-6

electricity use, i.e. the population centers. Thus, there is high exposure of populations to elevated ambient pollutant concentrations with resulting damage to human health. 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 could occur in places where cleaner fuels are more plentiful (whether natural gas, hydroelectricity, nuclear, or other renewable energy sources), then health and environmental dangers would be greatly reduced.

It is presumed that there are three general types of cross-border interconnections feasible in Northeast Asia [1], as illustrated in Fig. 1: from the Irkutsk/Lake Baikal region of Siberia through Mongolia to the Beijing area (Pathway A); extensions from Northeast China or Russia to the Democratic People's Republic of Korea (DPRK) and perhaps to the Republic of Korea (ROK) and Japan (Pathway B); and from far eastern Russia via Sakhalin Island to Hokkaido and thence to the rest of Japan (Pathway C).

Coal, natural gas, and hydropower are abundant in eastern Siberia and far eastern Russia. At present, there are 22 GW of installed hydroelectric capacity and 8 GW of coal thermal capacity installed in large power plants exceeding 1 GW [2]. This part of Russia is expected to undergo rapid growth in the future, however, due to its largely unexploited minerals and energy potential. An additional 12 GW of capacity are presently under construction (5 GW of hydro and 6 GW of coal thermal) with another 15 GW planned, including 2 GW of nuclear power [2]. Construction of most of this generating capacity is likely to go ahead even without electricity exports, because of local demand.

At present, however, electricity supply exceeds demand, so Russia wishes to generate revenues from the sale of excess electricity—thereby acquiring capital to build further plants in the future. Russia is currently 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. Later in this paper, we discuss some specific projects. Physical, economic, and

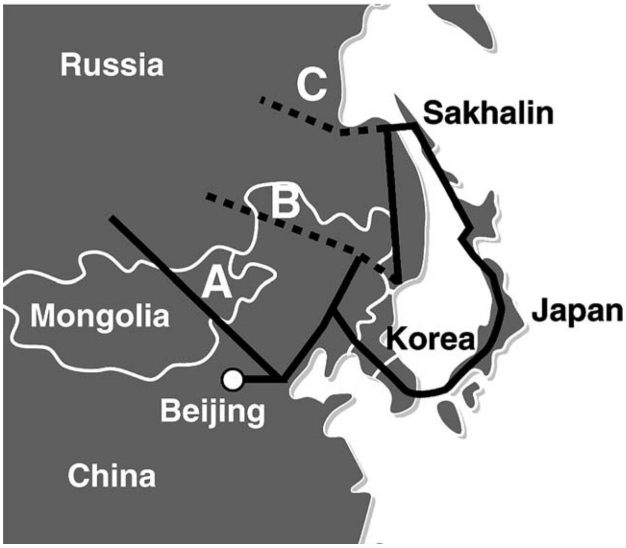

Fig. 1. Schematic of potential electricity grid interconnections in Northeast Asia [1].

political obstacles must undoubtedly be overcome before any of these projects can be realized. However, the focus of this paper is on the environmental benefits of such projects.

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 a 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 (0.1–0.3 TWh per year), and the capacities of the lines are insufficient for greatly increased transfers. Additional capacity to supply Erdenet and Ulan Bator is envisioned if Mongolian electricity demand should increase significantly. Jointly constructed hydroelectric plants are located on the border between China and the DPRK, but there are no physical linkages between the power systems. Thus, any initiative to create large-scale bulk power transfers 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 [3]. Table 1 presents information about current and projected fossil-fuel energy demand for power in the region from the RAINS-Asia computer model under mid-range energy forecasts [4,5]. For this work, we focus on the Northeast Plains (NEP) region of China, which we define to consist of the provinces of Heilongjiang, Jilin, Liaoning, and Inner Mongolia, together with the municipalities of Beijing and Tianjin.

The NEP 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 inevitable. Thus, the North China Power Group, for example, has more than 10 GW of new, large power plants planned or under construction at 10 sites [6]. 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 shows that coal use for power generation in the region is projected to grow by a massive 70% over the next 20 years. 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

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

Region	Year 2000			Year 2020		
	Coal	Oil	Gas	Coal	Oil	Gas
NEP/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: Ref. [5].

(by 7%), if Northeast China can obtain sufficient supplies from western provinces. The ROK 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 burden of power generation in the future. 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 of Northeast Asia. Hydroelectric resources are particularly plentiful. The technical potential of eastern Siberia is about 660 TWh yr^{-1}, of which 14% is presently utilized; and the technical potential of far eastern Russia is another 680 TWh yr^{-1}, of which only 2% is utilized [1]. In contrast, the hydroelectric resources of northern China are only about 20 TWh yr^{-1}. Natural gas reserves are also huge in eastern Russia, estimated at 2 Tcm, of which only a small amount is exploited today [1]. Natural-gas combined-cycle (NGCC) 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 planning to exploit tidal power; two large plants are under consideration for the future with capacities of 7 GW at Tugursk [1,2] and 80 GW at Penzhinsk [1,7]. Though Russia does hold sizeable coal deposits and presently uses coal for power generation in the region, it is likely that 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. With these concepts in mind, 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 sources and points of electricity use (demand centers);
- potential reductions in long-range pollutant transport and regional problems like acid rain and ozone;
- 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 the points 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 tidal power, offshore gas extraction, or undersea cables;
- additional power generation to overcome power losses in long-distance transfers;
- possible human health and ecosystem effects from transmission lines; and
- environmental effects associated with specific alternative energy sources (nuclear, hydro, etc.).

The assertion of this paper, however, is that the benefits will heavily outweigh the possible damages. 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 spatial scales will be discussed in general terms before an examination of individual project is undertaken. At that point, some of the actual merits of grid interconnections can be quantified and compared with the present-day magnitude of atmospheric emissions in the affected regions.

2. 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. Pathway A (Fig. 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 to some of the most polluted cities in northern China: Taiyuan, Lanzhou, and Yinchuan. Pathway B could supply electricity to the industrial NEP, where, again, are situated some of China’s most polluted cities: Shenyang, Changchun, and Harbin. All these cities regularly appear at the top of the list of cities with an air quality index of Grade III or worse than Grade III, signifying the highest levels of ambient air pollution. Pyongyang in the DPRK 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 be undoubtedly benefited, because rapid electricity demand growth is anticipated there with few attractive generation options. Pathway C in Fig. 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 would be greatest.

Table 2 summarizes recent ambient air-quality information for cities in Northeast China. These annual-average values were developed by the World Bank from daily measurements taken in the largest Chinese cities [8]. Normally, the data are converted into an air pollution index by the Chinese government, which is released to the public daily to communicate the state of current pollution levels [9]. Table 2 only includes those cities in the NEP region, as defined before in connection with Table 1, and two cities further to the west, Taiyuan and Lanzhou.

Some general observations can be made from Table 2. First, ambient levels of NO_x are high, but the data cannot be directly compared with WHO guideline values, because there is no recommended 24-h value [10]. NO_x concentrations are the fastest growing of all species, due to rapid expansion of the transportation systems, and NO_x emissions are of great concern to urban planners in China. Levels of SO_2 hover around the WHO guideline of 125 $\mu g\ m^{-3}$. Because these are the annual average of daily values, there are undoubtedly many days in a year when the SO_2 guidelines are exceeded. This is particularly true for the heavily industrialized, coal-burning cities like Taiyuan and Shenyang. Finally, concentrations of total suspended particles (TSP) are generally very high. Particulates in northern China are a combination of coal smoke and vehicle exhaust emissions—often compounded in the winter and spring months by wind-blown dust from the deserts and marginal cultivated lands of the western provinces. The WHO maintains that there is no threshold for human health effects [10], i.e. health damage can occur at any concentration.

Table 2
Annual daily average pollution concentrations in Chinese cities in 1995 (μg 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 guideline values [10]			
Annual	40[a]	50	–[b]
Daily	–	125	–[b]
Hourly	200[a]	–	–[b]

Source: Ref. [8].

[a] As NO_2.

[b] WHO no longer assigns a threshold to particulate levels.

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 the effects of inhalable particulate matter [11]. This is largely a mixture of primary particles and secondary sulfate aerosol (though ambient SO_2 itself is a health danger in some northeastern cities like Shenyang). It is generally accepted that there will be no alteration in the practices of 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 [12]. How effective this policy will be remains to be seen. Thus far, China had not implemented 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 [13], and year 2000 targets were met without extra effort [14]. 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 [15,16]. Among these trends are the following:

- the economic recession of 1997–1998 that swept through East and Southeast Asia and affected China to an extent not yet fully understood;

- 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 a number of 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 accepting imports of Russian-generated electricity than it was 5 or 10 yr ago, when electricity shortfalls were widespread. In addition, China's strides to integrate its own electricity network have made it less vulnerable to electricity shortages. Therefore—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 [11,17,18].

3. Regional-scale issues

Local-scale issues are the most important aspects of air pollution in Northeast Asia, because they are most intimately linked with damage to human health. However, there are a number of regional issues that are important over wider geographical scales. 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 even to 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 reactive organic compounds and 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 [3,4,19]. For many years, coal-fired power plants in northern and eastern China have been held responsible for a large proportion of the sulfur and acidity that is received in the Korean peninsula and Japan. The actual magnitude of this transported pollution is the subject of lively dispute between China and its neighbors to the east. Sulfur dioxide emissions and sulfur deposition have received the most attention. Though the regional sulfur source–receptor relationships for Northeast Asia are in dispute, certain aspects of the problem are clear. Sources in the NEP of China are strongly linked to sulfur deposition in the ROK, the DPRK, and Japan. According to the RAINS-Asia model [5], sources in the NEP are responsible for about 17% of sulfur deposition in the DPRK and 22% of sulfur deposition in Japan [3]. 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 and acid deposition from its own sources. Studies of acid deposition in China show a gradually expanding region of elevated sulfur deposition and low rainfall pH in northern China [19]. Rainfall acidity is partially neutralized by windblown mineral dust from western China [20].

Table 3 illustrates some of the features of the sulfur source–receptor relationship in Northeast Asia in simplified form [3]. This table shows that Shenyang receives 66% of its deposited sulfur from the surrounding NEP region. Similarly, Pyongyang receives 17% from NEP, 29% from sources in its own country, and 37% from the ROK. In percentage terms, greater benefit occurs when local emissions are low, 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.

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. Fig. 2 shows the distribution of SO_2 emissions in Northeast Asia [21]. It is clear that SO_2 emissions are high in Northeast China and contribute to high levels of sulfur deposition downwind. 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 [4]. 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.

Table 3
Simplified sulfur source–receptor relationships for Northeast Asia

Receptor region	Source region				
	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: Ref. [3]. Values represent the percentage of deposition in a particular receptor region that it is due to emission sources in a particular source region.

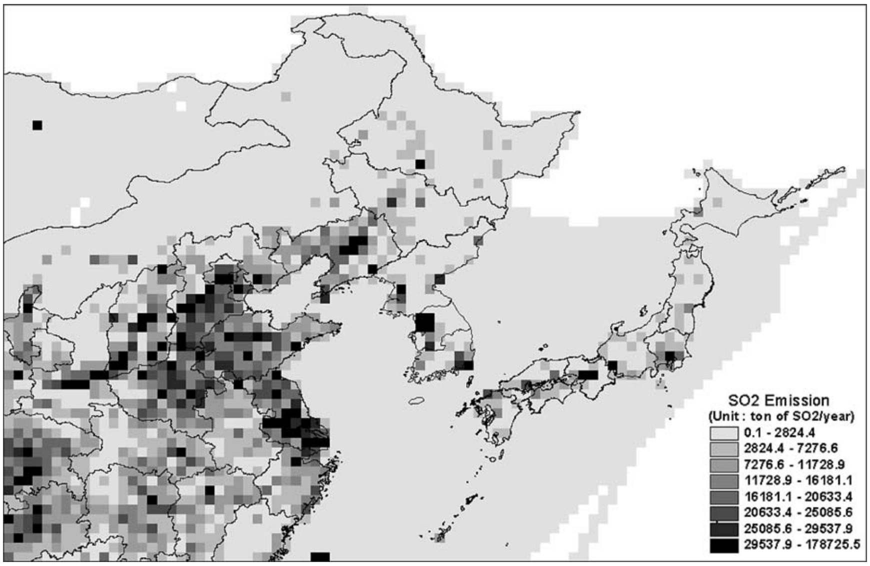

Fig. 2. Distribution of SO_2 emissions in Northeast Asia in 2000, excluding Russia [21].

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) are all burned in domestic stoves for cooking and, in the winter for heating [22]. 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 [23]. These emissions represent threats at all spatial scales: from inhalation by women and children in kitchens [24], through the regional problems of reduced visibility and insolation, to the global warming potentials of the direct greenhouse species methane and black carbon (BC) [25]. These species are also indirectly implicated in climate change 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. The availability of additional electricity throughout these rural areas would bring with it a variety of largely unappreciated benefits [26]. 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 of the electricity to rural communities could be of immense value. The US 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 BC. This is composed of submicron elemental carbon particles and is sometimes called soot [27]. Large quantities of BC are released during low-temperature combustion in inefficient stoves, cookers, kilns, etc. This is typical practice in rural China. The BC particles 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.

Fig. 3 shows the regional distribution of BC emissions in Northeast Asia [21,27]. The distribution is rather similar to the SO_2 distribution, in that they both mirror the distribution of coal use. However, the BC distribution is much more dispersed, as can be seen in Fig. 3 in the provinces to the northeast (e.g. Heilongjiang) and southwest (e.g. Hubei) of Beijing, due to the contribution from rural biofuel consumption. Rural electrification could gradually reduce these emissions and improve indoor air quality in the homes and kitchens of under-developed regions. The health benefits of this strategy are likely to be very large.

Another severe regional air pollution problem in Northeast Asia is ozone [28], caused by emissions of volatile organic compounds and NO_x. In the hot, humid, stagnant-air conditions of summertime Asia, 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 will soon be sufficiently high to cause serious crop damage [29]. One problem is that we have relatively little reliable monitoring data on which to build an understanding of ozone formation 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% [30].

Fig. 4 shows that the pattern of NO_x emissions in Northeast Asia is quite different from SO_2 and BC. This pollutant is strongly associated with the more developed cities of the region: Beijing, Shanghai, Seoul, Tokyo, etc., i.e. it is linked to the state of development of transportation systems. Though replacement of coal-fired electricity generation will have less of an effect on overall NO_x levels in these cities, because it cannot at present replace the transportation component, it may be equally or more valuable as a viable way to avert ozone formation. The control of NO_x from vehicles and the limitation of growth in the numbers of vehicles in Asian cities are equally daunting challenges for urban environmental managers.

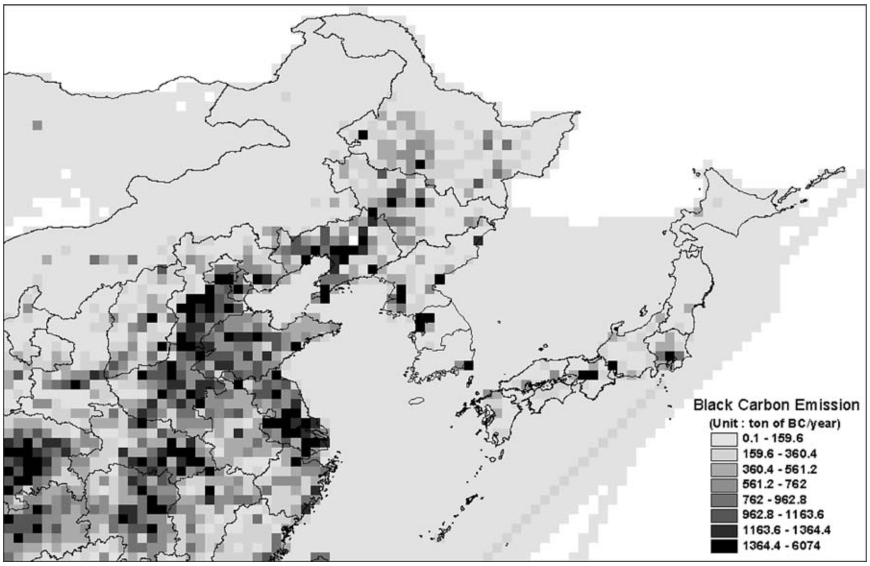

Fig. 3. Distribution of BC emissions in Northeast Asia in 2000, excluding Russia [21].

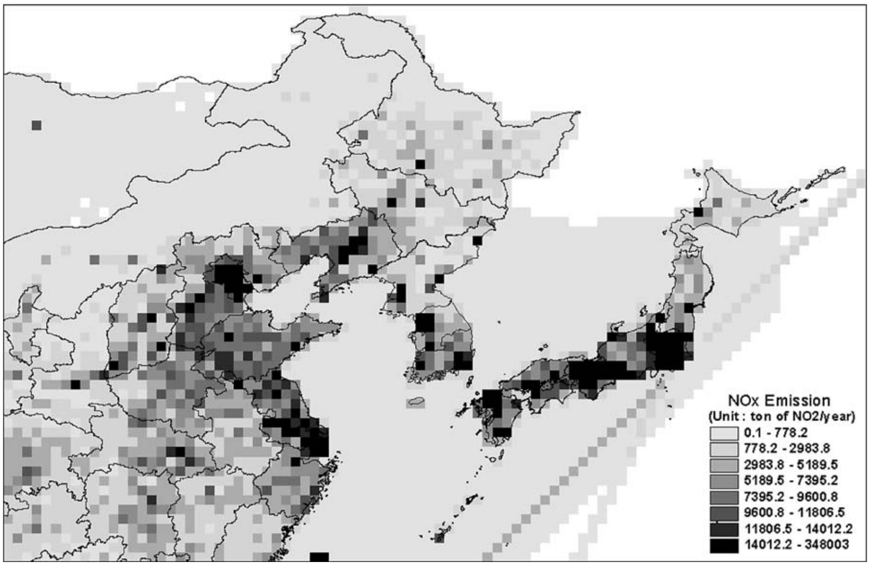

Fig. 4. Distribution of NO_x emissions in Northeast Asia in 2000, excluding Russia [21].

4. Global-scale issues

At 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 under Pathway C in Fig. 1. 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 eastern Russia through Sakhalin Island to Japan by submarine cable could supply a considerable amount of electricity from hydroelectric or nuclear power plants. Alternatively, NGCC plants using the gas reserves of Sakhalin Island are possible. These options would help to meet Japan’s joint electricity and greenhouse-gas targets.

Japan has limited domestic options to meet the electricity growth that is forecast 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 in Japan have heightened public concerns 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 unattainable. Japan’s CO_2 emissions from fossil-fuel consumption actually increased by 3% between 1995 and 1999 [31], and it is apparent that the present trajectory of greenhouse-gas emissions will make achievement of Japan’s Kyoto target a real challenge [32]. All these factors make interties to Russian low-carbon generating plants quite sensible for Japan on environmental grounds.

Other countries in the region are less concerned about this issue, because they are not required to reduce greenhouse-gas emissions under 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 [15] have led to a reduction in emissions of both CO_2 and CH_4 in China since 1996/1997 [16]. The decline in CO_2 emissions is primarily driven by the decline in coal consumption. This is shown in Fig. 5. The declining use of biofuels and the increased growth of forests had contributed to this trend. Overall, CO_2 emissions have declined by about 7% since 1996. Similarly, CH_4 emissions have fallen (by about 2% since 1997) mainly due to less coal mining. The implication of these trends is that China presently has little incentive to further reduce domestic emissions of greenhouse gases. It will require a return to economic vitality, renewed growth in coal consumption, and/or a new global compact on climate change to engage China on this issue.

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

- emissions of the gaseous greenhouse gases can be reduced (CO_2 mainly, but also CH_4 if coal mining can be reduced);
- potential reductions in emissions of BC can be achieved if rural fossil-fuel use and biofuel use are displaced by electrification;
- the net emission reductions will depend on the technology and fuel used to generate the electricity at the source;
- net emissions of CH_4 could conceivably increase if natural-gas combustion is the source of the electricity (from extraction, processing, and distribution of the gas) or decrease if coal-bed CH_4 releases are further averted; and
- there are energy and environmental policy issues specifically related to Japan's compliance with the Kyoto Protocol.

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 resultant effect on climate requires a

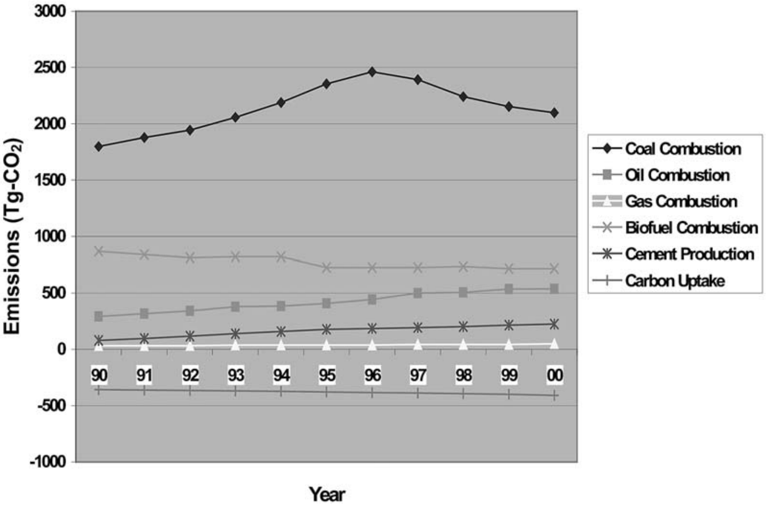

Fig. 5. Annual trends in CO_2 emissions in China, 1990–2000, by source type [16].

full accounting of changes in emissions of all greenhouse gases. This calculation should include, at minimum, CO_2, CH_4, BC, and sulfate aerosol (which has a negative radiative forcing). In other work we have shown that the net effect of reduced coal use in China could *increase* global warming [16,33], 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 rather perverse consequence for climate should not, however, detract from the benefits of these emission reductions at local and regional scales.

5. 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 [2]. 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 project concepts, three would utilize hydroelectric resources, two would use nuclear power, and one would use NGCC technology. Because NGCC plants are relatively fast and easy to construct, it is likely that they could offer greater potential than indicated here by the time a more mature gas industry has been developed in far eastern 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.

Fig. 6 shows 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 Fig. 6) would also pass through Ulan Bator and offer the potential of supplying electricity to that city. Option 1 might actually terminate at Tangshan City, 150 km northeast of Beijing, and link from there to the capital. Note also that Option 3 transmits electricity directly from Russia to the DPRK, without having to cross China's borders. Options 5 and 6 are not included in Fig. 6, because their transmission routes

Table 4
Prospective electricity ties from eastern 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	Nuclear	2015–2025	700	4/8	8.5
Primorye/ROK			1100		
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: Ref. [2].

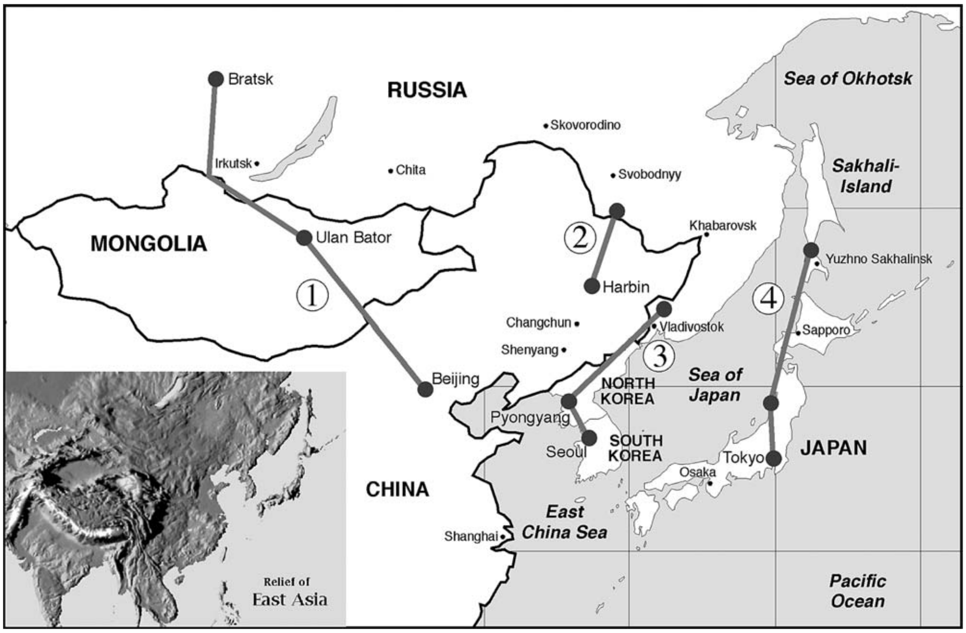

Fig. 6. Routes of proposed interconnection projects in Northeast Asia [2].

have not yet been determined. As stressed earlier, we do not pass judgment on the physical, political, or economic feasibility of these transmission options.

For each project the annual amounts of electricity available for transmission to neighboring countries are identified in the final column of Table 4. The total amounts are: 21 TWh (before 2015), 55 TWh (before 2025), and 90 TWh (beyond 2025). These quantities are uncertain, of course, and other examinations of this potential generate slightly different estimates. It is instructive to compare these amounts with current generation in the NEP region of China. In 1999 the six provinces and municipalities of Beijing, Heilongjiang, Inner Mongolia, Jilin, Liaoning, and Tianjin generated 203 TWh of electricity [34]. 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.

It can be concluded that the total amount of electricity likely to be available could supply a significant portion of Northeast China’s electricity needs. 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 them in the near term. So the air pollution problems of several Chinese cities could be 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-, oil-, and gas-fired power plants [5,26,35]. 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

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

Fuel	SO_2[a]	SO_2[b]	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[c]	0.51	0.07	0.08	3.5	0.18	96
Biofuel[c]	0.06	0.06	0.05	5.1	0.07	110

Sources: Refs. [5,25,27,34].

[a] Without emission controls.

[b] With controls, such as FGD for coal, low-sulfur oil, briquettes, etc.

[c] Residential fuel use, rather than power generation.

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.

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 BC. 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 organic carbon). Table 5 reveals the much higher emission rates of CO and BC for residential coal and biofuel combustion than from power generation. All these compounds play roles in local health damage, regional particle and photo-oxidant 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.

Estimates of the potential for regional emission reductions show that the benefits would be significant. The 21 TWh of electricity available annually before 2015 would avert approximately 10 million tons of coal use in Northeast China and 200 Gg of SO_2 emissions per year. This represents about 12% of the SO_2 emissions from power plants in the region and 6% of total SO_2 emissions in the region. The difference reminds us of the fact that much of the coal in China (about 50% in northeastern China) is used in the industrial sector.

In the regional context it is not likely that a large reduction in deposited sulfur or nitrogen would be achieved. Nor would recipient countries like the DPRK and Japan notice a large 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. But at both regional and global scales a significant contribution would be made to lift a portion of the burden of atmospheric pollution. Substantial local benefits could be achieved in a number of 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. 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.

Though the benefits are almost certainly positive overall, this analysis would be remiss without pointing out the potentially negative consequences. The clear benefits at the points of electricity use must be balanced against the environmental pollution created at the points 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, tidal power, undersea cables, and offshore gas extraction pose a potential set of marine ecosystem threats under some options. Long-distance power transfers imply power losses and therefore the need for additional power generation and the emissions that would accompany it. But, overall, because of the sparsely populated nature of much of the resource regions, it is likely that the damage or risk of damage would be slight and would affect natural ecosystems rather than human health. The only additional possible threat to human health would be the still-controversial hazard from high-voltage transmission lines. Prudent practice would suggest routing transmission lines away from populated areas.

6. Conclusions

This analysis has shown that increased electricity interconnections in Northeast Asia offer the potential to improve local, regional, and global air quality by moving the points 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. Plentiful clean energy resources are available in eastern Russia.

We can conclude with the following observations:

- The local benefits to human health in several (perhaps two to five) 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).
- Local health benefits in the countryside are possible from rural electrification to displace traditional fuels in Northeast China, Mongolia, and the DPRK.
- The health benefits at the points of electricity use are likely to heavily outweigh any ecosystem damages at the points of electricity generation.
- Regional air-quality benefits (acid rain, ozone) are likely to be positive but small.
- Global benefits are likely to be positive but very small; there is a possibility that the net effect

on global climate could be negative when all greenhouse-gas species are taken into account, due to the dominant effect of reducing sulfate aerosol.
- Japan could achieve some benefit in meeting its Kyoto Protocol commitment.
- Additional social benefits to under-developed parts of Northeast China, Mongolia, and the DPRK could be a by-product of greater access to electricity.

The achievement of regional environmental benefits, such as the ones that would accrue from enhanced grid interconnections, poses 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 Convention in Europe), in Asia the concept is in its infancy. Only recently has the Tripartite Environment Ministers Meeting (TEMM) among China, Japan, and Korea taken the first steps to foster regional environmental cooperation and sustainable development [36]. There is a long way to go before national policies can be harmonized and international agreements implemented in Northeast Asia. The harmonization of environmental regulations in the region is desirable, however [37]. It can eliminate the political instability that arises 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. Electricity exchanges across borders can be a positive force for respecting environmental integrity and harmonizing environmental policies and regulations.

Acknowledgements

The author is grateful to the Nautilus Institute of Berkeley, CA, for providing funds to prepare the original version of this paper, which was presented at the Nautilus Institute workshop on Power Grid Interconnection in Northeast Asia, Beijing, China, May 14-16, 2001 (see http://www.nautilus.org/energy/grid/index.html). Additional funding was provided by the US Department of Energy, Office of Fossil Energy. Argonne National Laboratory is operated by the University of Chicago for the US Department of Energy under Contract W-31-109-Eng-38.

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