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ENERGY POLICY

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Environmental impacts and benefits of regional power grid interconnections for China

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Abstract

This paper describes the development of China's power industry, present situation, environmental influences and potential benefits of regional power grid interconnections in China. Power plants in China are mainly thermal, burning fossil fuels especially coal which emit a great deal of pollutants and greenhouse gases such as SO_2, NO_x and CO_2. China leads all other countries in emissions of SO_2, CO_2, and the power industry is the largest contributor to these emissions. There are a number of environmental benefits through regional power grid interconnection. That is, the construction of small electricity generation capacity would be avoided; natural resources would be used to generate electricity on a regional scale; and generating sources can be separated from centers of electricity use, which will decrease emission of pollutants and greenhouse gases and help to reduce human exposure to elevated air pollutant concentrations. Therefore, gradually enlarged power grids, and power grid interconnection, should be part of the general pattern of power system development in China.

Keywords: Power; Environment; China

1. Introduction

China's power industry has entered into the era of large power networks, and power transmission technologies have also been improved greatly with the recent rapid development and construction of these power networks. At present, there are seven inter-provincial power grids (East China, Northeast, Central China, North China, Northwest, Sichuan–Chongqing and South China) and four independent provincial power networks (Shandong, Fujian, Xinjiang and Xizang (Tibet)) operating in mainland China. Large power grids now serve all cities and most villages throughout China (Fig. 1).

By the end of 2001, the total generating capacity in China was 338 GW (gigawatts), of which hydroelectric capacity (totaling 83 GW) accounted for 24.5%, thermal power (253 GW) accounted for 74.9%, and nuclear and other types of generation (at 2 GW or so) accounted for 0.6%. The total electricity generated in 2001 was 1,483,856 GWh (gigawatt-hours), of which thermal power supplied 1,204,478 GWh, accounting for 81.2% of total generation. Of thermal generation, 95% was from coal-fired power plants. China's reliance on coal-fired power has caused serious environmental problems, as will be described later in this paper.

By the end of 2003, the total generating capacity in China was expected to be approximately 370 GW. Power supply, however, is still poor in many provinces. At present, overall, there is a slight shortage of power-supply nationwide. The projected electricity demand and supply situation in 2003 in each region and province of China is shown in Table 1. There are 15 provinces throughout all regions of China facing lack of electricity except the Northeast (Zhang, 2003).

There is no doubt that demand for electricity in China will continue to increase dramatically in the future due to the rapid pace of economic development. Fig. 2 shows the pattern of power industry development (generation and capacity) over the past 20-plus years relative to the pattern of overall gross domestic product (GDP) growth (Wang et al., 2002). By the year 2020, China's GDP is expected to increase by 200% over that of 2000, meaning that annual average GDP growth rates

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0301-4215/$ - see front matter © 2004 Published by Elsevier Ltd.
doi:10.1016/j.enpol.2004.02.018

are projected to average 7.2% or so till 2020. Under this projection, China's GDP in 2020 will be increased to 35,000 billion RMB (Chinese currency). In order to meet this economic growth target, it is necessary for China's electric power industry to maintain its recent rapid rate of development. Total nationwide electricity consumption in 2010 is projected to rise to about 2700 billion kWh, with generating capacity increasing to about 600 GW. It is estimated that total annual electricity demand in 2020 will have grown to about 4000 billion kWh, with total national generating capacity reaching about 900 GW. On average, 30 GW of generating capacity will need to be added each year till 2020 to reach these capacity goals (Hu, 2003). This rate of addition is approximately twice the rate of recent capacity expansion, and is thus a great challenge for the Chinese power sector.

Interconnections between large regional power grids in China, as well as interconnection between regional nets and independent provincial nets, are presently being considered and implemented. Four directional (east, west, south and north) interconnections and circumjacent interconnections among nets are being constructed in order to allow power from West China to flow to the major consuming areas in the East, to allow power to be shared between North and South China during times when available capacity in one region coincides with high demand in the other, and to allow power from the central Three Gorges Hydropower project to be distributed in all four directions. By the year 2005, power grid interconnection for all of China except Xinjiang, Tibet, Hainan and Taiwan will be preliminarily complete (State Power Corporation of China, 2002).

Even though power grid interconnections in China become nationwide, electricity will still mainly come from coal-fired power plants, which produce more pollutants and greenhouse gases than most other sources. But if international power grid interconnections can be established in Northeast Asia, the use of natural resources could be optimized for electricity generation over a larger geographical area. This useful environmental option is discussed below in Section 3.2.

Fig. 1. China's power grids (adapted from State Power Corporation of China, 2002 and Beijing Datang Power Generation Co. Ltd).

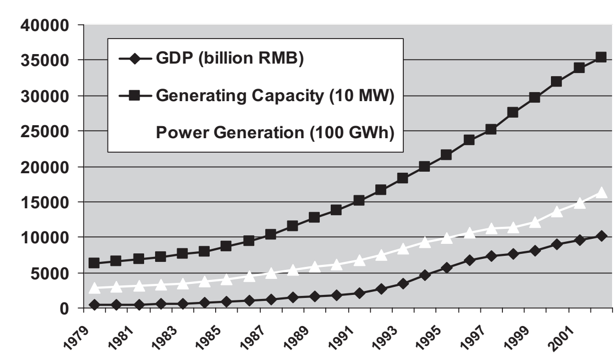

Fig. 2. Comparison of trends in China's power industry development with trends in GDP, 1979 to 2002 (adapted from National Bureau of Statistics of China and State Power Corporation of China).

Table 1
The status of electricity supply and demand by province in China, 2003

Region	Provinces where demand exceeds supply (15)	Provinces where demand and supply are roughly in balance (8)	Provinces in which supply somewhat exceeds demand (10)
North China	Shanxi, Southern part of Hebei, Western part of In-Mongolia	Beijing, Tianjing, North part of Hebei, Shandong	
Northeast			Heilongjiang, Jilin, Liaoning, East part of In-Mongolia
Northwest	Gansu, Qinghai, Ningxia	Xinjiang	Shanxi
Central China	Henan, Chongqing, Sichuan	Hubei, Hunan,	Jiangxi
South China	Guangdong, Guizhou, Yunnan		Guangxi, Hainan
Eastern China	Jiangsu, Zhejiang, Shanghai		Anhui, Fujian
Others		Tibet	

2. Environmental impacts of China's power industry

2.1. Environmental impacts power generation

Power demand all over the world currently relies primarily on fossil fuel combustion (thermal power), only secondarily on hydro and nuclear sources. The amount of electricity generated from wind, solar, tidal and geothermal energy accounts for a very small percentage of the current global total. There is no doubt that large-scale power generation inevitably causes environmental impacts at varying levels of severity.

Table 2 shows a subjective environmental ranking of various power-generation technologies. Power generation from solar energy, wind energy, tidal energy and biomass is renewable and sustainable. The environmental impacts of these generation technologies are relatively light. Hydroelectric generation is or should be renewable as it burns no fuel and is powered by solar energy via the hydrologic cycle, but prevention of sedimentation in hydroelectric reservoirs is essential if generation capacity is to be maintained. Reservoirs in which the areas flooded contain considerable biomass (e.g., forests or peat), however, they can lead to significant greenhouse gas emissions in the form of methane and carbon dioxide from decaying biomass. The environmental impacts of geothermal power systems are generally easily managed (e.g., through re-injection of condensates once heat has been extracted), so it makes sense to utilize this resource where it is available.

In contrast, utilization of all fossil fuels is unsustainable by definition. The combustion of fossil fuels, especially coal, can produce heavy environmental impacts through smoke dust (particulate matter), sulfur dioxide, NO_x, and CO_2 emissions. In addition, some hot wastewater, as well as fly ash and bottom ash, are also produced by coal-fired power plants. Generators can use advanced technologies and equipment to reduce dust, SO_2 and NO_x emissions from fossil fuel-fired power plants to minimum levels, but these technologies are generally not widely used in China today. So far, China's power generation equipment cannot use coal without excessive CO_2 production. If coal technology improves such that CO_2 emissions can practically and economically be minimized, or CO_2 from coal-fired generation can be collected and adequately disposed, prospects for future development of coal-fired power would be improved.

Nuclear power plants do not emit many air pollutants, but their operation results in the production of long-lived radioactive wastes, and pose safety problems. If the radioactive waste storage problem in China (or regionally) is solved, and if in addition "inherently" safe reactor designs are achieved, uranium mining impacts are reduced, nuclear weapons proliferation issues are fully addressed, and shipment of radioactive materials becomes safe, prospects for future deployment of nuclear power generation would be improved (Goodland, 1996).

Table 2
Environmental ranking of various power-generation technologies

Environmental rank (impact from least to most)	Remark
Solar energy	Renewable and sustainable
Wind energy	
Tidal energy	
Biomass	
Hydro	Renewable and potentially sustainable
Geothermal	
Natural gas	Non-renewable and unsustainable
Oil	
Coal	
Nuclear	

2.2. Environmental impacts caused by China's thermal power plants

As mentioned above, most power in China currently is generated in power plants burning fossil fuels, especially coal. In 2002, for example, power generated using fossil fuels in China totaled 1342 billion kWh, accounting for 81.8% of a total of 1640 billion kWh. The key environmental impacts caused by China's power industry are the results of air pollutant emissions from coal-fired power generation. Fig. 3 shows the trends of national SO_2 and dust emissions from thermal power plant operation compared with the development of the power industry (electricity generation and capacity) and with total nationwide SO_2 emissions over the past two decades.

As shown in Fig. 3, with the increase of thermal power electricity over the past 20 years, coal consumption has

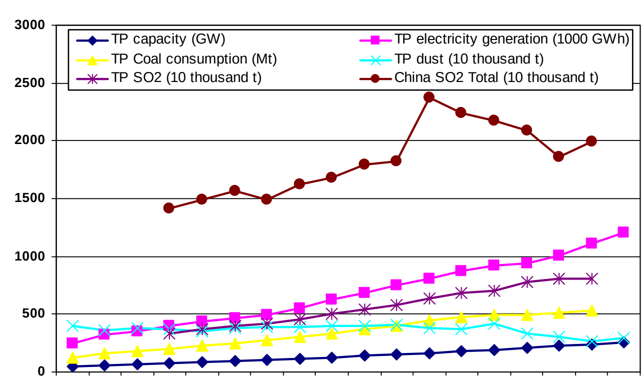

Fig. 3. SO_2 and dust emitted from thermal power plants (TP) in China (adapted from State Power Information Network, 2002, National Bureau of Statistics of China, Annual Statistics Data, http://www.stats.gov.cn).

Table 3
SO_2 concentration in ambient air and sulfur precipitation contributed by thermal power plants in China in 2000

Province	SO_2 concentration (μg/m^3)				Sulfur in precipitation (g/m^2-year)			
	City aver.	City max.	Regional aver.	Regional max.	City aver.	City max.	Regional aver.	Regional max.
Beijing	19.5	19.5	4.5	19.5	2.9	2.9	1.1	2.9
Tianjing	24.2	24.2	7.7	24.2	4.1	4.1	1.8	4.1
Hebei	12.8	24.2	3.8	12.8	2.2	4.1	1	4.1
Shanxi (NW)	6.4	21.2	2.3	21.2	1.2	2.9	0.6	2.9
In-Mongolia	5.6	16.4	0.3	16.4	0.8	2.1	0.1	2.1
Liaoning	5.6	14.2	2.1	14.2	0.9	1.9	0.5	1.9
Jilin	1.7	4.6	0.5	4.6	0.3	0.6	0.1	0.6
Heilongjiang	1.5	3.3	0.2	3.3	0.2	0.4	0.1	0.4
Shanghai	15.2	36.1	15.2	36.1	10.2	10.3	4.5	10.3
Jiangsu	10.8	25.4	4.9	25.4	2.7	4.6	1.5	4.6
Zhejiang	4.3	18.9	1.7	18.9	1.1	4.9	0.5	4.9
Anhui	3.3	8.8	1.5	10.1	0.8	1.8	0.5	2.1
Fujian	1.3	5.1	0.6	5.1	0.3	1	0.3	1
Jiangxi	2.7	6.1	0.6	6.1	0.7	1.1	0.4	1.1
Shandong	9.2	17.4	5.2	17.4	2	3.5	1.5	3.5
Henan	7	22.5	2.5	22.5	1.4	3.5	0.8	3.5
Hubei	1.9	18.3	0.9	18.3	0.6	3	0.4	3
Hunan	2	9.4	0.6	9.4	0.6	1.7	0.4	1.7
Guangdong	6.5	23.4	1.7	23.4	1.2	3.5	0.5	3.5
Guangxi	1.6	5.1	0.8	25.2	0.4	0.9	0.3	3.7
Hainan	0.2	0.9	0	0.9	0	0.1	0	0.1
Sichuan	6.6	38.2	1.3	38.2	1.5	7.4	0.4	7.4
Guizhou	5.9	19.4	1.7	20.6	1.4	4.1	0.7	4.1
Yunnan	1.6	9.2	0.2	9.2	0.3	1.8	0.1	1.8
Tibet	0	0	0	0	0	0	0	0
Shanxi (N)	11.5	38	1.9	38	1.8	6.3	0.5	6.3
Gansu	1.1	4.4	0.2	4.4	0.2	0.5	0.1	0.5
Qinghai	1.5	1.5	0	1.5	0.2	0.2	0	0.2
Ningxia	5.1	8.4	0.8	8.4	0.7	1.1	0.2	1.1
Xinjiang	1.4	7.1	0.1	7.1	0.2	0.9	0	0.9
China	4.9	38.2	0.8	38.2	1	10.2	0.2	10.2

increased steadily. In 2002 total coal consumption in China was more than 1.3 billion tons, of which about 50% was used for power generation. At present, about 8 million tons of SO_2 are emitted from coal-fired power plants each year, which accounts for about 50% of total industrial SO_2 emissions in China. The 3 million tons or so of dust emitted from coal-fired power plants each year amounts to about one-third of total industrial dust (particulate matter) emissions. It is estimated that in China over 4 million tons per year of NO_x is emitted into the air from fossil-fueled power generation.

Emissions of SO_2, NO_x and dust from coal-fired power plants can cause increases in ambient concentrations of these air pollutants. Table 3 shows SO_2 concentrations in the ambient air and sulfur precipitation contributed by thermal power plants by province in China as of 2000. Emissions of pollutants from thermal power plants were major contributors to these ambient levels of pollution. In most regions of North and Northeast China, and particularly in cities, the amount of ambient SO_2 concentration contributed just by coal-fired power plants is higher than the total average ambient concentration over all of China.

China's emissions of SO_2, CO_2, and substances that deplete the O_3 (ozone) layer, are ranked, respectively, the first, second and first in the listing of global emissions by country (Wang, 2002). Without doubt, the power industry is the largest contributor to these emissions. In addition, SO_2 emitted from coal-fired power plants is one of the principal precursors in acid-rain formation. Acid rain has been spreading in China in recent years. The area of China affected by acid rain has extended from a few districts in the southwest as of the 1980s, to a situation where most parts of southwest and southern China are now affected, as well as much of central and eastern China (Fig. 4). Districts in China where the annual pH of precipitation averages below 5.6 now account for about 40% of the entire national land area (Zhu and Tan, 2002).

3. Environmental benefits of power grid interconnection for China

There are a number of benefits that can be obtained from regional power grid interconnection (Zhang, 1995;

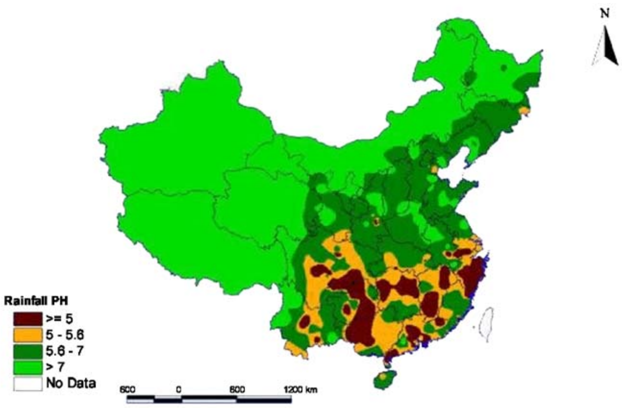

Fig. 4. pH values of precipitation in China in 2001.

Han et al., 2000). The paper will focus on environment issues.

There are three main environmental benefits related to regional power grid interconnection. First, the need for some new power generation capacity will be avoided. This will avoid damage that would have been incurred during the construction of these new power plants. Second, grid interconnection allows the use of natural resources to be optimized to generate electricity over a larger geographical area. This can reduce the overall environmental impacts caused by power generation. Finally, generation sources can be further separated from the major areas of electricity use (e.g., cities). This separation can help to minimize damage to human health resulting from power sector emissions.

3.1. Avoid damage due to some new power sources construction

Regional power grid interconnection can offer the opportunity for mutual compensation of spare (reserve) generating capacity. This can reduce the spare generating capacity on each individual single network. In a study done by Podkovalnikov (2002), the interconnection of RFE-NEC-RK (Russian Far Eastern, Northeastern China, and Republic Korea) power grids will save generating capacity and investment (Table 4). The interconnected grid will save 7.21 GW, of which the 3.7 GW saved in the NEC accounts for 51.3%. That means that generation capacity can be reduced in NEC without a reduction in the power supply available there. The 3.7 GW saved accounts for around one-tenth of the total northeast China power network capacity.

There is only one large hydro station over 1 GW (Fengman Hydro) on the NEC grid. Most of the electricity used in NEC is generated by coal combustion. Saving 3.7 GW of capacity can therefore avoid direct damage (such as dust, discharge of wastewater, noise, resettlement of people, land occupation, ecosystem damage, etc.) incurred in construction of 3.7 GW of power-generating sources, as well as indirect impacts incurred by related construction such as building of roads to power plants, extended or new coal mining, transportation of coal and oil, and so on. Similarly, a saving of 0.76 GW of capacity in the RFE and 2.75 GW in the RK can also avoid direct and indirect damage related to construction of power plants.

Table 4
Capacity and investment saving due to interconnection (Podkovalnikov, 2002)

	RFE	NEC	RK
Capacity saving (GW)	0.76	3.7	2.75
Investment saving, $Bin.	0.7	4	4.1

3.2. Reduce environmental impacts due to power generation

The use of coal-fired power plants results in emissions of SO_2, NO_x, CO_2 and dust, which in turn result in ambient air pollution and can make the earth warmer through their contribution to climate change. At present, more than 80% of the electricity used in China is produced from fossil fuel combustion. This proportion is even higher in the northern parts of China. Air pollutants from coal-fired power plants have caused serious environmental problems, such as the poor air quality in Shenyang, Taiyuan, Lanzhou, Tianjin, Beijing, and other Chinese cities that is notorious around the world, and is largely the result of coal combustion (Economic and Social Commission for Asia and the Pacific of United Nations, 2002).

Chinese coal resources are mainly distributed in northern China, where they account for 64% of China's total coal resources. Shanxi province and the western part of Inner Mongolia have the richest coal resources in northern China. The second-richest regions are the northwest and southwest areas, accounting for 12% and 10.7% of total resources respectively (Table 5).

China's petroleum and natural gas resources are distributed mainly in the northeast and north parts of the country, which account for 48.3% and 18.2% of the total for those resources, respectively. Petroleum and natural gas are cleaner sources of energy for electricity generation than coal. Unfortunately, the availability of these resources is relatively poor in China, so it is impossible for China to use petroleum and natural gas as principal sources for electricity generation.

Hydro-electric energy resources are distributed primarily in Southwest China, which accounts for 70% of this national resource. As a result, China's hydro-energy resources are distant from the core region of consumers in the northeast. In fact, Northeast China is relatively

Table 5
Distribution of energy resources in China (Zhu and Tan, 2001)

Region	Fraction of energy resource (percent)			
	Coal	Hydro	Petroleum and natural gas	Total
North	64.0	1.8	14.4	43.9
Northeast	3.1	1.8	48.3	3.8
East	6.5	4.4	18.2	6.0
South and central	3.7	9.5	2.5	5.6
Southwest	10.7	70.0	2.5	28.6
Northwest	12.0	12.5	14.1	12.1

Note: North includes Beijing, Tianjing, Hebei, Shanxi (N), Inner Mongolia.
Northeast includes Liaoning, Jilin, Heilongjiang.
East includes Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong.
South and Central includes Hebei, Hubei, Hunan, Guangdong, Guangxi, Hainan.
Southwest includes Chongqing, Sichuan, Guizhou, Yunnan, Tibet.
Northwest includes Shanxi (NW), Gansu, Qinghai, Ningxia, Xinjiang.

poorly supplied with energy resources, having only 3.1% of the total energy resources of China. Obviously, with limited hydro-electricity resources, with no nuclear experience, and with no plans to utilize scarce, expensive oil and gas resources, any increases in electricity demand in the area will have to be met by coal-fired power plants if the power grid of Northeast China is not interconnected.

The energy resources of the Russian Far East and East Siberia are, however, very much more abundant than those in neighboring regions of other countries, particularly hydroelectric resources. The technical potential for hydroelectric development in East Siberia is about 660 TWh yr^{-1}, of which 14% is currently utilized, while the technical potential for hydro in Far Eastern Russia is 680 TWh yr^{-1}, of which only 2% is utilized. Natural gas reserves are also huge in eastern Russia, estimated at 2 Tcm, out of which almost none are presently exploited (Streets, 2003). As a result, the Russian Far East and East Siberia have abundant supplies of cleaner energy, namely hydro and natural gas.

At present there are 22 GW of installed hydroelectric capacity and 8 GW of coal-fired thermal generating capacity in the region. Russia is also considering exploiting tidal power, with more than 80 GW of capacity under consideration for the future. The far eastern part of Russia is expected to undergo rapid economic growth in the future, due to its largely unexploited mineral and energy potential. As a result, there are an additional 12 GW of capacity presently under construction (about 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, in order to meet expected increases in local demand. At present, however, electricity supply exceeds demand, so Russia wishes to generate ancillary revenues from the sale of excess electricity—thereby acquiring capital to build additional plants in 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 neighboring regions of the other countries would not come from coal-fired plants (Streets, 2003; Podkovalnikov, 2002).

In spite of the relatively good supply of electricity in the Northeast network, the North China grid is suffering from a shortage of electricity at present. The North China Grid and Northeast China Grid have been interconnected since May 13, 2001 (Li and Xiao, 2001). If the Northeast China Grid interconnects with that of the Russian Far East, imported electricity from Russia can be transported to the North China Grid through the Northeast China Grid. Of course, interconnection between the North China grid and the Russian Far East is also a possible scheme.

If regional power grid interconnections are realized and energy resources can be shared in different countries, the connected regions (neighboring countries) can use their overall energy resources to generate electricity in an optimized fashion. For example, North China and Northeast China can import hydroelectricity from Russia. This will greatly reduce total SO_2, NO_x, CO_2 and dust emissions (Table 6). The interconnection is not only useful for improving air quality in these regions, but is also good for abatement of acid rain in other regions of China (due to transport of acid gases from Northeast China to other parts of China) and of global climate change. Furthermore, use of the interconnection will also eliminate environmental impacts related to the avoided extraction of coal in China. The environmental impacts from transporting coal from coal mines to power plants also are avoided. In addition, if regional interconnection is realized electricity supplies in the interconnected portions of China are likely to be

Table 6
Reduction of emissions as a result of substitution of hydro for coal-fired electricity in Northeast China

Capacity	Coal saved (Mt)	SO_2 (t)	NO_x (t)	Dust (t)	CO_2 (Mt)
1 GW	2.42	28 350	18 275	8260	5.03
3 GW	7.26	85 050	54 825	24 780	15.10
5 GW	12.1	141 750	91 375	41 300	25.17

Note: Annual operation 5000 h; emission index based average level in 2002 in China from Environmental Monitoring General Station for Electric Power, 2002 Environmental State for Power Industry in China.

more plentiful. More citizens in North and Northeast China will have the opportunity to use electricity for home heating in the winter instead of coal, resulting in reduced indoor and local air pollution. If electricity is not expensive, it will be used by farmers in rural areas to displace bio-fuel and straw combustion for home heating and cooking. All of these trends would help improve ambient air quality greatly.

3.3. Minimize damage to human health

Environmental damage to human health is closely related to pollutant concentrations. If pollutant concentrations in the ambient air are lower than Grade II of China's national standard, then damage to human health resulting from pollution is considered acceptable. In 2001, there were 341 cities in China where pollutant concentrations are monitored, of which 114 (33.4%) have attained or are better than the national standards for Grade II. The air quality in 10 cities, including Haikou, Sanya and Zhaoqing, attained Grade I levels, while the air quality in an additional 114 cities (33.4% of the total monitored) was at the Grade III level. The air quality in 113 cities (33.2%) was worse than Grade III levels. These figures underscore the fact that air pollution in Chinese cities is a rather serious problem.

Particulate matter (or dust) remains the key pollutant affecting air quality in China. The annual concentration of the urban particulates in 64.1% of the cities exceeded Grade II. The annual concentration of particulate matter in 101 cities (29.7%) exceeded Grade III levels (Fig. 5) (State Environmental Protection Administration of China, 2001). The cities with high concentrations of airborne particulates are mainly located in Xinjiang, Qinghai, Gansu, Shanxi, Inner Mongolia, Shaanxi, Ningxia and Hebei provinces (Fig. 6). As a result, most parts of North China (including Northwest and Northeast China) have serious particulate pollution problems.

The cities where the annual concentration of SO_2 did not reach national Grade II standards as of 2001

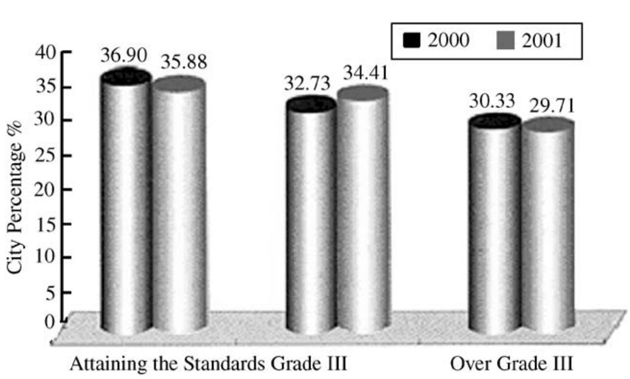

Fig. 5. Percentage of 341 cities meeting particulate grade standards in urban air in China.

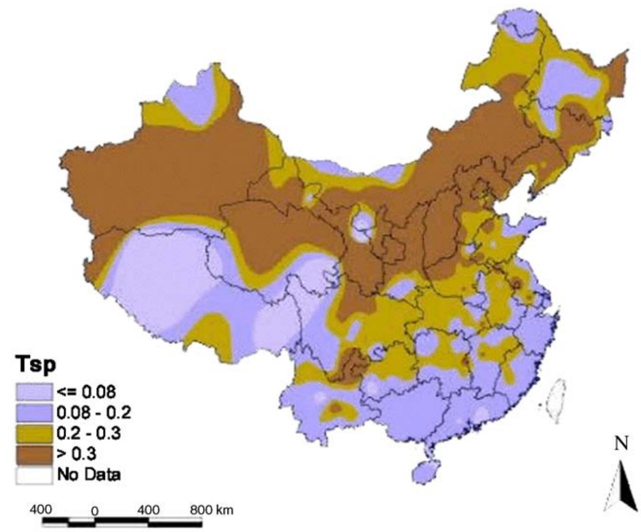

Fig. 6. Total suspended particulate (TSP) concentrations in China.

account for 19.4% of the cities included in SO_2 statistics. The cities exceeding national Grade III standards account for 9.7% of the total sample. Of the 341 cities sampled (including county level municipalities), 64 cities are located in the SO_2 pollution control zone, and 118 fall into the acid-rain control zone. The cities in the SO_2 pollution control zone and the acid-rain control zone where the annual concentration of SO_2 attained Grade II standards account, respectively, for 48.4 and 79.7% of the cities covered by pollution statistics. Compared with statistics from the year 2000, the percentage of cities in the SO_2 pollution control zone attaining standards increased somewhat, and the percentage of the cities with worse than Grade III SO_2 pollution declined by 4.3% (Fig. 7). The cities with serious SO_2 pollution are mainly located in Shanxi, Hebei, Guizhou, Chongqing and parts of Gansu, Shaanxi, Sichuan, Hubei, Guangxi and Inner Mongolia provinces (Fig. 8).

Comparing Fig. 8 with Table 3, we can conclude that SO_2 concentration caused by operation of coal-fired power plants contributes to high ambient levels of SO_2 concentrations in most cities. The primary reason for this correlation is that in most regions of China, existing power plants are usually geographically co-located with the centers of electricity use; that is, power plants are located in urban centers. In order to ease combined access to labor, transport, and electricity supply, there has generally been no effort in China to distance power plants from population centers. These urban power plants are typically large, coal-fired stations with only electrostatic precipitators (and sometimes Venturi water film precipitators) for control of particulate matter, and with no SO_2 or NO_x controls. The location of coal-fired power plants in urban centers results in a maximum exposure of populations to elevated ambient pollutant concentrations, and impairs human health, largely

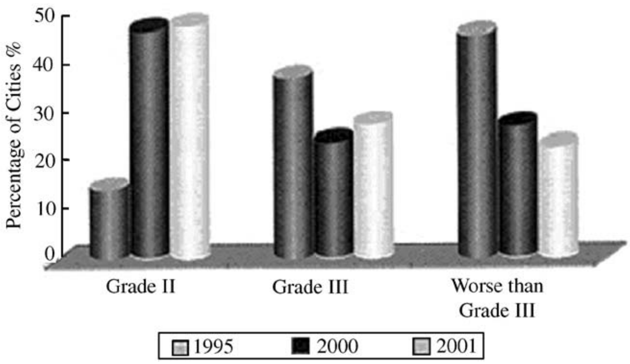

Fig. 7. Attainment of SO_2 pollution Grade levels by cities in the SO_2 pollution control zone of China.

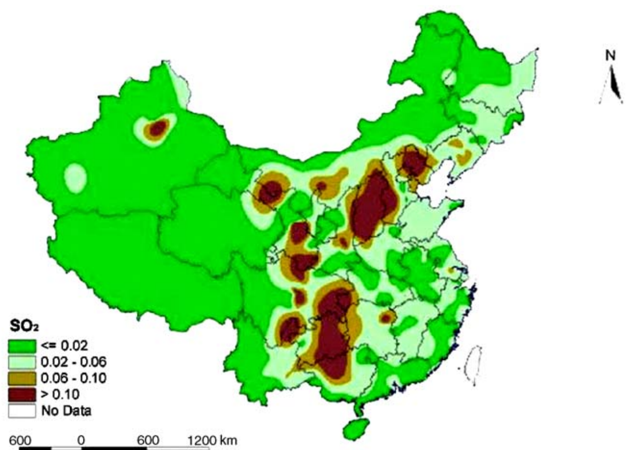

Fig. 8. SO_2 concentrations by location in China, 2001.

through the presence of inhalable particulate matter, which is largely a mixture of primary particles and secondary sulfate (through ambient SO_2 itself is a health danger in some northeastern cities).

If electricity grid interconnections are enhanced, new generating plants can increasingly be separated from points of electricity use, namely urban centers. This separation will help to alleviate human exposure to elevated air pollutant concentrations. Of course, grid interconnection and increased transmission losses will tend to increase environmental impacts slightly. Still, it appears that interconnection should offer a net environmental benefit.

3.4. Environmental impacts of regional power grid interconnections

Regional power grid interconnections require the construction of at least some new transmission lines and transformer substations. These lines and substations will occupy some land. In some instances, a relatively few people will need to be relocated. During construction, dust, noise, and vegetation damage may occur. In general, these environmental impacts are transient and are not heavy. Construction-related environmental impacts can be acceptable if some reasonable control measures are used.

Operation of power grids can produce electrical fields and magnetic fields near transmission lines. Up to now, however, there is no persuasive evidence to confirm that electric and magnetic fields near transmission lines have harmful impacts on human health.

4. Conclusions

Gradually enlarged power grids, and power grid interconnection, have been part of the general pattern of power system development in China. Regional power grid interconnections and shared energy resources (including China, Russia, and other nations in Northeast Asia) may offer at least 3 types of environmental benefits for China. First, the construction of 3.7 GW of electricity generation capacity will be avoided. This will in turn avoid the direct and indirect environmental damage that would be caused by construction in China of new power plants to meet the same capacity requirements. Second, regional optimization of the use of natural resources to generate electricity as China imports hydroelectricity from Russia and in so doing reduces environmental impacts caused by power generation in China. The use of imported power will particularly help improve ambient air quality in North (including northwest and northeast) China. And third, generating sources can be separated from centers of electricity use. Doing so will reduce damage to human health.

Acknowledgements

The research described in this paper was supported in part by The Nautilus Institute for Security and Sustainability, and is based on a paper for the Third Workshop on Power Grid Interconnection in Northeast Asia.

References

Economic and Social Commission for Asia and the Pacific of United Nations, 2002. Air quality in Asia and the Pacific 44–48.

Goodland, R., 1996. Environmental sustainability: a challenge to the hydropower industry. In: Proceedings of International Conference on Environmental Protection of Electric Power, October, 1996, Nanjing, China, pp. 129–144.

Han, Z., Xue, Y., Qiu, J., 2000. A series of reports on 2000 international large power grid conference-the state and perspective of power grid interconnection. Automation of Electric Power system 24, 1–4.

Hu, Z., 2003. Analysis on the state of power supply and demand in China. China Electric Power News, April 1, 2003.

Li, Z., Xiao, Q., 2001. Successful start-up of interconnection of North and Northeast power grids.China. Electric Power News, May 15.

Podkovalnikov, S., 2002. RFE-NEC-DPRK-RK" power grid interconnection. Presentation at the 2nd Workshop on PGI in NEA, May 6–8, 2002, Shenzhen, China.

State Environmental Protection Administration of China, 2001. China Environmental State Report.

State Power Corporation of China, 2002. China Power Enterprises Union, Running after sun. People's Daily News Press.

State Power Information Network, 2002. 2001's basic data for power industry production, http://www.sp.com.cn/zgdl/dltj/b0102.htm.

Streets, D.G., 2003. Environmental benefit of electricity grid interconnections in Northeast Asia. Energy 28, 789–807.

Wang, J., 2002. Several questions about environmental safe and economic development harmonization. Nature Friend 1, 1–3.

Wang, Z., Zhu, F., Liu, S., 2002. Thermal Power, SO_2 Environmental Impact and Control Measures. China Environmental Sciences Press, p. 7.

Zhang, F., 1995. Inter-regional and international power network-a world tread of power system development. China Electric Power 12, 2–5.

Zhang, G., 2003. Powerful measures would be taken in order to relieve electricity shortage. China Electric Power News, May 13, 2003.

Zhu, F., Tan, G., 2001. Large scale development in west China and sustainable development of power industry. China Electric Power 34, 1–5.

Zhu, F., Tan, G., 2002. Joining WTO and sustainable development of electricity generation industry. Electric Power Environmental Protection 4, 1–4.