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# Environmental Issues for Regional Power Systems in Northeast Asia

***Prepared for the***

***Third Workshop on Northeast Asia Power Grid Interconnections***

***Hosted by the***

**The Nautilus Institute for Security and Sustainability,**

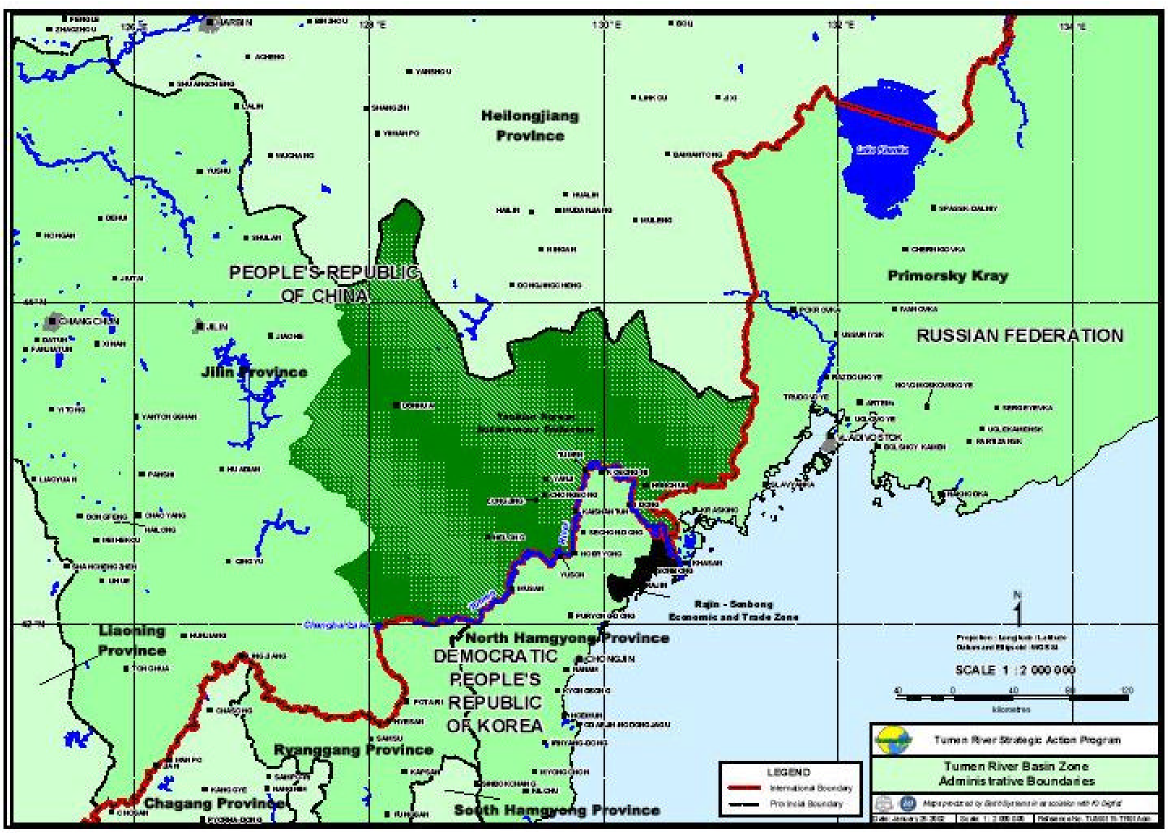
**The WWF Far Eastern Branch, and**

**The Economic Research Institute**

**September 30 - October 3, 2003, Vladivostok, Russian Federation**

***Prepared by:***

**David F. Von Hippel and James H. Williams, Nautilus Institute**



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**Prepared for the Third Workshop on Northeast Asia Power Grid Interconnections**

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**Workshop held September 30 to October 3, 2003, in Vladivostok, the Russian Federation**

## ABSTRACT

The Third Workshop on Northeast Asia Power Grid Interconnections, held from September 30 to October 3 of 2003, focused on the potential environmental impacts of power grid interconnection developments in Northeast Asia. Power grid interconnections will have both positive and negative impacts on the environment. A full accounting and assessment of the net impacts of grid interconnections requires an evaluation not only of the construction and operating impacts of the power line built to interconnect the power grids of the region, but also of the electricity generation systems in the interconnected countries and the fuel supply (and waste disposal) systems that support them. This paper provides a generic overview of the potential environmental benefits and impacts of grid interconnections in a number of areas, including air pollution, water pollution, solid and hazardous wastes, land use, biodiversity and wildlife, and human health. The final two sections of the paper summarize institutional issues associated with the environmental performance and regulation of grid interconnections, and offer ideas as to "next steps" in the collaborative assessment of the possible environmental, economic, and technical performance of a grid interconnection.

Note: Map on the title page of this report showing the Tumen River area of the border region of China, the DPRK, and the Russian Federation was obtained from the TumenNET (Tumen River Strategic Action Program, UNOPS/GEF/UNDP) web site http://www.iodigital.com.au/tumennet/download.asp.

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# 1. Introduction

The 2003 Workshop on Northeast Asia Power Grid Interconnections, held from September 30 to October 3, 2003, represented the third time that a group of researchers have assembled to consider the potential of electric power grids between the countries of Northeast Asia. While past workshops in the Grid Interconnection series have focused on technical and economic issues related to grid interconnection, the 2003 workshop focused on the environmental implications—positive and negative—of grid interconnections in Northeast Asia. This report provides a generic listing of the potential environmental implications of grid interconnections, as well as some initial indications of potential environmental impacts and benefits of grid interconnections in Northeast Asia.

## ***1.1. Overview and Goal of this Report***

The establishment of interconnections between the electrical grids of adjoining countries may be of interest for a host of technical, political and economic reasons, including, but now limited to:

- Enhancing the stability (reducing the potential for grid collapse) of one or both (or all) of the grids that are interconnected.
- Offering opportunities for energy resource-rich areas to sell power to areas not as well endowed with domestic energy supplies.
- Increasing the diversity of electricity supply in one or both (or all) of the interconnected nations.
- Offering opportunities for power trading when the times of peak electricity demand (for example, daily or seasonal) in the interconnected countries are complementary.
- Offering opportunities to avoid the construction of generation and/or transmission facilities in one or both (or all) of the interconnected nations, which is particularly valuable where siting of new facilities is problematic.
- Reducing the overall cost of power generation in the interconnected nations.
- Increasing the economic interdependence of the interconnected nations (thus, it is hoped increasing contact and improving relations between the nations).

Electrical grid interconnections also, however, will have local, regional and global environmental impacts, as well as benefits, that must be considered in any exploration of interconnection prospects. These impacts and benefits may occur at any or all points in the fuel chain, from extraction of fuels for electricity generation, to construction and operation of plants and construction and operation of transmission facilities. Environmental considerations have sometimes received less emphasis in energy planning than technical, economic, and (often) political issues. In the case of grid interconnections in Northeast Asia, however, the early consideration of environmental impacts in evaluating interconnection options will help to identify key potential problems—including sensitive ecosystems to be traversed by the power lines—as well as potential opportunities that could enhance the interconnection project—including credits for avoided air pollutant and greenhouse gas emissions.

The purpose of this report is to identify the environmental impacts and benefits that should be considered in a complete assessment of the costs and benefits of grid interconnections in Northeast Asia. As such, this report provides primarily generic introductions to potential environmental impacts across the fuel cycles that could be affected by the construction and operation of international power lines. In addition, this report treats very generally some of the Northeast Asia-specific environmental costs and benefits that might accrue to interconnection projects in the region. As such, the primary objective of this report is to familiarize the participants in the Third Workshop on Northeast Asia Power Grid Interconnections with the main environmental issues that will need to be considered in detail as the modeling, and preliminary and advanced feasibility studies, of interconnection options proceed. This report, suitably augmented with region-specific information (see Section 1.4, below) could therefore serve as a "framework" of sorts for the environmental assessment of grid interconnection options. The hope is that this familiarity will help participants in the Workshop, and in an ongoing Regional Working Group studying the interconnection issue, to prepare the data needed for collaborative modeling of environmental and other costs and impacts of interconnection, and will also help participants to be able to use this familiarity with environmental issues to "speak the same language" as collaborative modeling proceeds.

## ***1.2. Background***

This introductory section provides, as general background to the issues, a brief discussion of the interconnection concept in Northeast Asia, a summary of the themes covered in previous Grid Interconnection workshops, a very brief discussion of the potential power line routings for grid interconnections, a listing (which is elaborated on in later sections of this report) of potential environmental issues associated with grid interconnections, both generally and in Northeast Asia, and a listing of some of the key initial rationales for grid interconnection in the region, from the environmental standpoint.

### 1.2.1. The interconnection concept for Northeast Asia

A number of different proposals have been made for interconnecting the electricity grids of the countries of Northeast Asia. These proposals generally are focused on generating electricity in the relatively resource-rich regions of Eastern Russia, including the Russian Far East (RFE) and Siberia, and moving that electricity to the major urban electricity markets in East Asia, notably the Republic of Korea (ROK), Northeast China, and (sometimes) Japan. Some of the proposals that have been suggested

A number of grid interconnection options have been proposed that would link the RFE with the ROK and the Democratic Peoples' Republic of Korea (DPRK)[1]. Options also include more elaborate transmission line proposals involving Japan (including a transmission "ring" surrounding the Sea of Japan/Korea East Sea), as well as segments of transmission line linking

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[1] See, for example, S. Podkovalnikov, Study for "Russian Far East–Korea People Democratic Republic–Republic of Korea" Power Grid Connection: Analysis of Current Status. Prepared for the Second Workshop on Regional Power Grid Interconnection in Northeast Asia, May 6th to 8th, 2002 in Shenzhen, China. This paper is presented in the section of www.nautilus.org devoted to the results of the Second Grid Interconnection Workshop as http://www.nautilus.org/energy/grid/2002Workshop/Podkovalnikov_020617.PDF.

portions of one or more Chinese regional grids to the RFE or other parts of eastern Russia. Key elements of, and considerations for, grid interconnection include the following[2]:

- *The cost of the transmission line*. Transmission line costs per kilometer vary depending on whether the line is AC (alternating current) or DC (direct current), the capacity of the line, the terrain crossed by the line, and the types of conductors (wires carrying current) and towers used. As a rough rule of thumb, a line capable of carrying on the order of 1000 MW of power might cost $250,000 to $500,000 per kilometer, meaning that a line linking the RFE with the ROK, and passing through the DPRK, would cost on the order of $0.5 to $1 Billion.
- *The cost of converter stations*. If part of the line is DC (superior in cost and performance to AC if the transmission distances are long enough), at least two converter stations must be used to convert AC power to DC for transmission, then back again to AC for use. AC-DC-AC converter stations may also be needed to provide interfaces between systems of different frequencies (see Figure 1-1), and/or to enable the partial isolation of interconnected grids from each other[3]. Converter station costs have been decreasing with improvements in electronics technology, but are on the order of $100 million per 1000 MW of capacity. The technical issues associated with grid interconnection, and with the operation of AC-DC-AC interconnections, are considerable[4].
- *The seasonal availability of generation and generating capacity in the interconnected countries*. For example, the RFE has available capacity (above the amount it needs to provide for its own power needs) in the summer, but little available capacity in the winter. The situation in the ROK is reversed—there is little or no excess capacity in the summer, but available capacity in the winter.
- *The capital costs of the power plants that the long-distance transmission will avoid*. The availability of the power from the transmission link will allow one or more countries to avoid building new power plants to meet peak and/or baseload power needs. The higher these "avoided capacity costs" are, the more economic the link will be.
- *The capital costs of any power plants added specifically to provide power for the link*.
- *The fuel and operating costs of the power plants that will feed into the transmission link relative to the costs for the power plants not run because of the availability of power from the link*. That is, the net generation costs avoided by the interconnection.
- *Environmental or other considerations related to transmission line and/or generation siting and operation*. Depending on what power plant operation and/or capacity is avoided, the grid interconnection may be credited with avoided pollutant emissions, transmission bottlenecks, or power plant siting difficulties. For example, providing hydroelectric power

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[2] Parts of this discussion are adapted from Regional Energy Infrastructure Proposals and the DPRK Energy Sector: Opportunities and Constraints, prepared for the KEI-KIEP Policy Forum on "Northeast Asian Energy Cooperation", Washington, DC, January 9, 2003, by David Von Hippel and Peter Hayes.

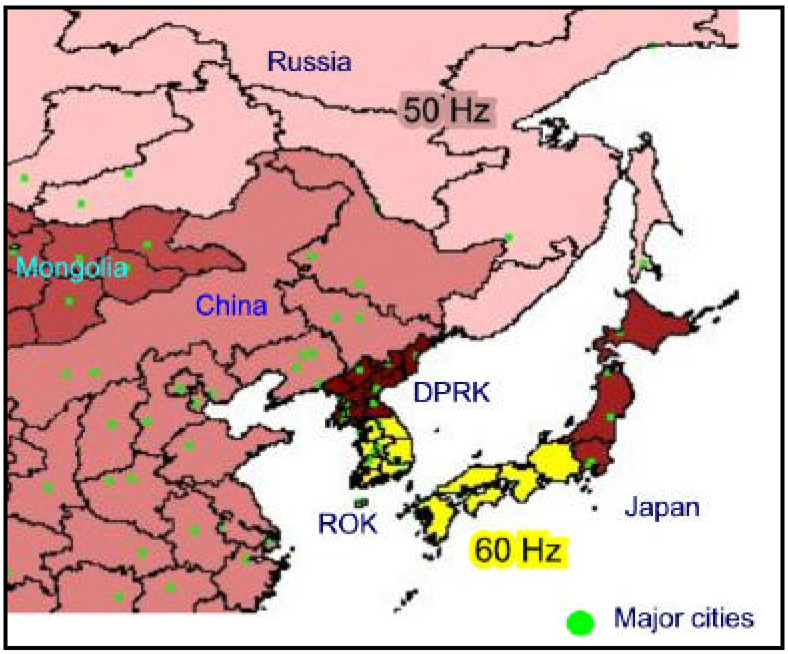
[3] Note that while the DPRK electricity grid is designed to operate at a frequency of 60 Hertz (Hz), it in fact in recent years has operated at frequencies varying in time and location. Frequencies ranging from 52 Hz to 48 Hz and lower on the DPRK grid have been measured. Variations in frequency of more than a small fraction of a Hz are rare in most electricity grids today.

[4] For example, see papers by Felix Wu, Lev Koshcheev, and J.K. Park prepared for the First Workshop on Power Grid Interconnection in Northeast Asia, held in May, 2001, in Beijing. See www.nautilus.org.

from the RFE that avoids coal-fired generation in China or the Democratic People's Republic of Korea (DPRK) will avoid the emissions of greenhouse gases and local/regional air pollutants. Similarly, displacing new peaking capacity in the ROK with the capacity of a transmission line from the RFE avoids the transmission and siting constraints faced by the ROK in expanding its fleet of nuclear reactors. These considerations are the main focus of this paper.

- *Institutional and pricing arrangements*. The arrangements needed to provide a multi-lateral institution for the operation of a Northeast Asia transmission link are decidedly non-trivial, as are arrangements for agreeing on power pricing (and rents for power transmission across national territories. Some international examples for such arrangements exist, but none operate in a political climate similar to that in Northeast Asia[5].

***Figure 1-1: Frequency Distribution of the Electricity Grids of Northeast Asia[6]***




Initial analyses of the economic potential of grid interconnections between the RFE and the ROK through the DPRK (and in some cases involving China) indicate that grid interconnections may be cost-effective on purely economic grounds, or may be cost-effective ways to reduce overall regional greenhouse gas and other air pollutant emissions[7]. Much depends on what is assumed about the parameters discussed above, and more detailed feasibility studies and modeling of the power systems to be interconnected, including assessment and

[5] For example, see papers by Karsten Neuhoff and Ivar Wangensteen prepared for the First Workshop on Power Grid Interconnection in Northeast Asia, held in May, 2001, in Beijing. See www.nautilus.org.

[6] P. Hayes (2000), Regional Energy Security and the DPRK Electric Power Grid. Briefing to US Under-Secretary of Energy Ernest Moniz dated June 7, 2000.

[7] See the paper Estimated Costs and Benefits of Power Grid Interconnections in Northeast Asia, prepared by David F. Von Hippel for the First Workshop on Power Grid Interconnection in Northeast Asia, held in May, 2001, in Beijing, and the 2002 paper by S. Podkovalnikov (prepared for the Second Grid Workshop) referenced above. See www.nautilus.org.

modeling of environmental benefits and impacts, is needed to better characterize the net benefits (or costs) of the different interconnection schemes.

For the purpose of this paper, it is assumed that the most practical medium-term (5 to 10 years) grid interconnection option to be implemented will be one that interconnects the Russian Far East and ROK grids through the DPRK, possibly with limited connections also to the DPRK grid and to the grid in Northeast China. Such an interconnection could:

- Allow the RFE to export power from capacity that exceeds RFE domestic needs (and later, capacity built for exporting power) to markets in the ROK and possibly Northeast China.
- Provide grid support and a source of emergency back-up power for the light water reactors (LWRs) being built by the Korean Peninsula Energy Development Organization (KEDO) at Simpo (sometimes referred to as the Kumho site) in the DPRK.
- Possibly provide some power to the DPRK (for example, for special industrial zones).
- Offer the opportunity for the ROK to export power to the RFE and/or China during the winter (when power demand in the ROK is lower).
- Allow the reduction in capacity requirements in the ROK (for summer peaking) and/or in the RFE (for winter peaking) and possibly in China. ROK constraints on both South-to-North transmission routes and new sites for nuclear facilities help to make this prospect attractive.
- Potentially avoid pollutant emissions from fossil power plants in the interconnected countries.

#### 1.2.2. Themes and results of previous Grid workshops

The Nautilus Institute (Nautilus) and the Chinese State Power Corporation co-hosted the First Workshop on Power Grid Interconnection in Northeast Asia in Beijing in May of 2001. Participants included engineers from the Chinese utility in the area of Northeast China adjacent to the DPRK, as well as representatives of Chinese central agencies, scholars, electrical engineers from the DPRK, leading power system engineers from the ROK, power system experts from Japan and Russia, and economists and energy policy analysts from the Northeast Asia region, from Europe, and from the United States. This first Grid Workshop focused on providing a general background on grid interconnection issues in a number of areas, including exploring the motivations for grid interconnections from the perspective of existing international grid arrangements, economic and environmental issues associated with interconnections, grid stability issues, issues related to the use of nuclear reactors within small power grids, and grid financing. Presentation of the status of power grids and interconnection investigations in each of the countries of the region were also included.

As such, the First Grid Workshop provided a forum for the sharing of the latest research related to regional grid interconnection issues among workshop participants from the region, as well as information about the development of the electricity sector in each of the region's nations. Through the workshop’s activities, common knowledge was developed among workshop participants regarding the technical aspects of grid connections, energy and electricity markets (such as global trends in market deregulation), and other general issues (for example, climate change, acid rain, and local air pollution) related to electricity generation and grid operation. The workshop also provided the opportunity for participants to hear the perspectives of individual countries on potential power grid interconnections.

The May 2001 workshop also provided training and background for regional researchers on technical issues associated with grid interconnection. This technical element was particularly valuable in providing information on general issues associated with the development and operation of regional international power grids, as well as on the realities of the KEDO reactor/power grid interactions and plausible ROK-DPRK grid connections. In particular, information was provided on the link between grid reliability and the scale of a nuclear power plant operating within a grid, as well as the linkage between grid reliability and the safe operation of LWR nuclear power plants. The Final Report and the workshop materials and commissioned papers from the First Regional Grid Interconnection Workshop are available at http://www.nautilus.org/energy/grid/2002Workshop/index.html

The Second Workshop on Power Grid Interconnection in Northeast Asia was held from May 6th to 8th, 2002 in Shenzhen, China. The workshop was co-hosted by Professor Felix Wu and the Tsinghua University - Hong Kong University Shenzhen Power System Research Institute. A number of participants from the first Workshop were present in Shenzhen as well, along with additional experts from China, the ROK, and Russia. The second Workshop included presentations and discussions on:

- The current status of economic and technical issues associated with potential power grid interconnections in each of the countries represented, and the findings of an analysis of a Russia-DPRK-ROK interconnection route prepared by Dr. Sergei Podkovalnikov and his colleagues from the Energy Systems Institute of the Siberian Branch of the Russian Academy of Sciences[8].
- The analytical methodologies that might be used in an ongoing joint pre-feasibility study of grid interconnection, along with potential data sharing mechanisms, including the sharing of data for use in software tools for network stability analysis. Specific data needs for collaborative technical and economic analysis were also discussed
- The creation of a pre-feasibility working group of Russians, North Koreans, South Koreans and Chinese to work specifically on preliminary quantitative analysis of interconnection options.
- Specific safety and grid stability issues related to the KEDO LWR power plants currently under construction in the DPRK, and how those issues intersect with incentives and options for construction of international power grid interconnections on the Korean peninsula.

During and subsequent to the Second workshop, participants provided ideas for the scope and organization of collaborative research on grid interconnections. These ideas will be addressed, and, it is hoped, moved forward during the discussions to be held during the upcoming Third workshop. The Final Report and workshop materials, including commissioned papers, for the Second Regional Grid Workshop are available at http://www.nautilus.org/energy/grid/2002Workshop/index.html.

[8] See footnote 1 for full reference.

### 1.2.3. Possible transmission line routes

Several different routes for transmission lines connecting the Russian Far East with the DPRK, the ROK, and possibly Northeast China, have been proposed. In his paper prepared for the Second Grid Workshop, Dr. Sergei Podkovalnikov described a potential routing that uses existing railroad right-of-ways, and is germane to both the location and focus of the Third Grid Workshop. This routing connects to the RFE grid at Vladivostok, and follows existing railroads southwestward largely along the seacoast to the border of the Russian Federation and the DPRK. There the route continues along the East Coast of the DPRK, turning just north of Wonsan to head approximately west across the Korean peninsula to the Pyongyang area. From the Pyongyang area, the route goes roughly south to the ROK border, and from there into the Seoul area. Of course, alternative routings, particularly from the Wonsan area south, are possible, including a route that goes generally south from Wonsan to the ROK border. For a transmission interconnection involving China, a route described in Dr. Podkovalnikov's paper goes west from Vladivostok to Harbin in Northeast China, then south-southwest to Shenyang, east-southeast along the West Coast of the DPRK to the Pyongyang area, then on across the demilitarized zone (DMZ) to the Seoul area.

The topography traversed by an RFE-DPRK-ROK line originating in Vladivostok is varied. From Vladivostok, the route goes along an area of coastal plains, valleys and hills to the border, where it would have to traverse or somehow skirt a major wetlands area. In the DPRK, the route goes along a coastline largely bordered by relatively mountainous topography, and the route across the Korean peninsula to the Pyongyang area is particularly rugged terrain, meaning the route might need to go through river valleys as much as possible. From Pyongyang to Seoul, the route could largely follow the coastal plain, skirting hills and small mountains. For a line traversing China, the route from the Russian Far East (if it started in Vladivostok) would traverse at least one fairly major mountain range and an area of forests and varied topography before reaching Harbin. From Habin, the route to Shenyang is largely an area of plains. From Shenyang to the DPRK border at Sinuiju, the route goes through a narrow valley and across a range of mountains, before traversing the coastal plain area of the western shore of the DPRK, which includes substantial areas of swamps and wetlands, to the Pyongyang area.

### 1.2.4. Potential environmental benefits and impacts of grid interconnections in NE Asia

Most of the potential classes of environmental benefits and impacts of grid interconnections in Northeast Asia are treated in more detail in later sections of this report. A brief listing of these benefits and impacts is presented here by way of an introduction to the variety of environmental issues that should be considered.

- **Air pollutant** emissions including local air pollutants, regional air pollutants (such as the precursors of acid precipitation and some particulate emissions), and greenhouse gases. Modest quantities of emissions may be produced during power line construction, but the main influence of grid interconnections on air pollutant emissions will be through the impact of transmission interconnections on which power plants are run where and when in the interconnected nations.

- **Water pollution** impacts, including erosion and water pollutants produced as a result of power line operation, and incremental water pollution from power generation and fuel extraction/storage.
- **Solid waste** impacts, mainly coal ash and high- and low-level nuclear wastes from electricity generation, but also including wastes from fuel extraction and possibly from power line construction.
- **Land-use** impacts, including the restriction of uses of land through which a power line passes, and potential avoided land-use impacts from electricity generation or fuel extraction facilities avoided by the use of an interconnection.
- **Wildlife/biodiversity** impacts, including the potential impacts of power line construction and operation on flora and fauna in the power line area, and potential avoided impacts due to avoided generation and fuel extraction.
- **Human health** impacts, including the impacts of electromagnetic fields (EMFs) from power lines on humans living and working in the power line vicinity, and avoided human health impacts through avoided air and water pollution.

As is clear from even these brief discussions of classes of impacts, electricity grid interconnections offer the potential for impacts at each different part of the fuel cycle. The full range of fuel cycle steps at which impacts can occur or be avoided include power line construction, operation of the power line, construction and operation net of avoided construction and operation for the power plants feeding the grid interconnection (or which are avoided by the use of the line), impacts related to fuel supplies for power plants, and impacts related to power plant wastes.

#### 1.2.5. Environmental impacts as a key element of feasibility assessment

Some of the reasons why environmental impacts, and the assessment of potential environmental impacts, are potentially quite important to the success of a grid interconnection project in Northeast Asia have been touched upon above. Among these reasons is the possibility that a line connecting the power grids of the region will pass through the narrow and environmentally-sensitive area near where the Russian Federation, China, and the DPRK come together; any infrastructure development in that area will be of considerable concern from an ecological impacts point of view, and will therefore be subject to considerable scrutiny. In addition, the environmental benefits of an interconnection (including reduction of air pollutant and greenhouse gas emissions, as well as avoided power facility siting-related impacts in the ROK and possibly elsewhere) may both help to justify the project politically and environmentally, or may provide opportunities for financing parts of the project through special international funds (such as the Global Environment Facility). Finally, as discussed briefly later in this paper and in a separate presentation being prepared for the 3rd Grid Workshop, a thorough assessment of environmental impacts is likely to be a prerequisite for financing of all or part of an interconnection project by lenders, particularly multilateral lenders such as the World Bank and the Asian Development Bank[9]. Given the substantial international political and cultural

[9] See J.H. Williams (2003), International Best Practices for Assessing and Reducing the Environmental Impacts of High-Voltage Transmission Lines, prepared for the Third Workshop on Power Grid Interconnection in Northeast Asia, Vladivostok, Russia,

sensitivities in the region, the environmental impacts of an interconnection project, and the distribution of impacts among the participating countries, must be clearly assessed and understood before work can begin on interconnection infrastructure itself.

#### 1.2.6. Impact tradeoffs

As the listing of potential environmental costs and benefits of a transmission interconnection presented above suggests, a transmission grid interconnection in Northeast Asia is likely to offer a number of environmental tradeoffs. Tradeoff in impacts of power grids operating independently or with a transmission link will occur both between types and among the connected locations. Any environmental assessment of an interconnection must therefore include a clearly-presented description of how impacts compare between connected and non-connected electricity infrastructure development scenarios, both across the different places to be connected and across the different parts of the fuel cycle. Offering the reviewer the opportunity to judge the relative environmental costs and benefits of different options in this way will contribute to a clear understanding of how these costs and benefits are distributed, and, as a consequence, what technical and economic modifications might need to be made in order that the interconnection project is acceptable to all participants.

### *1.3. Guide to Remainder of Report*

The remainder of this Report is organized as follows:

- **Section 2** summarizes the potential air pollutant impacts of grid interconnection, and introduces some of the methods and data sources that can be used to evaluate those impacts.
- **Section 3** focuses on the potential impacts of grid interconnections on water pollution and water quality.
- **Section 4** looks at the potential impacts of grid interconnections on the generation of different types of solid and hazardous wastes, including nuclear wastes.
- **Section 5** identifies the potential impacts of grid interconnections on land use.
- **Section 6** examines some of the potential impacts of grid interconnections on biodiversity, and wildlife.
- **Section 7** summarizes some of the potential impacts, both direct and indirect, of grid interconnections on human health.
- **Section 8** identifies some of the potential institutional issues associated with the environmental performance and regulation of grid interconnections, both in general and, in a preliminary fashion, in the Northeast Asia context.
- **Section 9** presents a number of suggested “Next Steps” for consideration in the exploration of the environmental impacts of grid interconnections in Northeast Asia.
- **Attachments** to this report provide a preliminary data collection template for information needed for an environmental assessment of grid interconnections, a listing of additional

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September 30 to October 3, 2003, and available at http://www.nautilus.org/energy/grid/2003Workshop/Env_Best_Practices_Williams_final.pdf.

references covering some of the topics presented here, links to information sources on the world-wide web that may be of use for environmental assessments of grid interconnections, and other resources.

### *1.4. A Framework for Future Study*

It should be noted that this report is not intended in large part to be a definitive statement of the environmental impacts of grid interconnections in the region. Rather, this report presents a generic treatment of the topic that refers to much more detailed results of the Third Workshop on Northeast Asia Power Grid Interconnections, as those results are reflected in the papers and presentations by workshop participants from the Northeast Asia region and beyond. This paper is therefore designed to serve as an overall framework for future study of the environmental impacts of transmission lines linking the region. Papers submitted for the Workshop by participants are referenced, and in some cases very briefly summarized, within the appropriate sections of this report, and links, when available, are provided to those papers from within this report.

## 2. Air Pollution Impacts of Grid Interconnections

Grid interconnections may, depending on how they are configured, create or avoid (or both) air pollution impacts as a results of their operation. The section of this report that follows reviews the potential local, regional, and global air pollution impacts and benefits from grid interconnections in Northeast Asia, summarizes how the net air pollutant emissions or emissions savings (and their impacts) might be assessed, and briefly presents potential strategies for maximizing air pollution benefits of a grid interconnection in Northeast Asia.

Of course, detailed evaluation of air pollution impacts at each of these scales can be extremely complex, and many reports and, indeed, entire volumes have been dedicated to the evaluation of air pollutant emissions and impacts. The brief treatment below is therefore intended only as an overview, to be considered as a generic structure underpinned by much more detailed work in the field by a number of authors, including contributors to previous Nautilus workshops (notable examples in this area are the work of Dr. David Streets and Dr. Greg Carmichael[10]), as well as many others.

[10] Examples of work by these authors prepared for the Nautilus ESENA (Energy, Security and the Environment in Northeast Asia) project include Gregory Carmichael and Richard Arndt (1997), Baseline Assessment of Acid Deposition in Northeast Asia (available as http://www.nautilus.org/papers/energy/carmichaelESENAY1.pdf), and David G. Streets (1997) Energy and Acid Rain Projections for Northeast Asia (available as http://www.nautilus.org/papers/energy/streetsESENAY1.html). In addition, Dr. Streets prepared a paper entitled Environmental Aspects of Electricity Grid Interconnection in Northeast Asia for the First Grid Workshop (2001, available as http://www.nautilus.org/energy/grid/papers/streets.pdf). Dr. Streets has revised and updated the latter paper as "Environmental benefits of electricity grid interconnections in Northeast Asia" for the journal Energy, volume 28 (2003), pages 789–807. Streets' work identifies in a largely qualitative manner the likely air pollution benefits of interconnection in Northeast Asia, using the same local/regional/global pollutant division provided here, but provides a great deal of detail, background, and analysis that is beyond the scope of the current paper.

## *2.1. Introduction*

Consideration of the net impacts of grid interconnections on air pollution involves consideration of net emissions of in several pollutant classes and over the range of emissions sources that comprise the full electricity generation/transmission/distribution fuel cycle. The type, timing, and location of pollutant emissions need to be considered, as all of these elements play a role in determining the impacts of emissions. Even a transmission interconnection that yields the same emissions, relative to a no-interconnection alternative, can offer significant benefits if the power plants that run more to feed power to the interconnection are far from population centers and/or sensitive environmental areas, and the power plants that are operated less because the interconnection is used are located near population centers.

For analytical purposes, one way to divide the different types of air pollutant emissions is by the scale of their impacts. A typical division of air pollutants by their scale of impacts is as follows:

- **Local air pollutants**, which typically largely affect the area in or near which they are emitted. Local air pollutants can have impacts on human, animal, and plant health, as well as on visibility, and can also have impacts.
- **Regional air pollutants**, including those pollutants that are play a role in acid precipitation, can have a variety of impacts on health, ecosystems, and structures.
- **Global air pollutants**, particularly greenhouse gases, can affect global climate.

Individual air pollutant species may have impacts and one or more of these scales. The subsections 2.2 through 2.4 provide brief discussions of air pollutants related to grid interconnections and their impacts at each of these scales. Additional sections of this chapter provide summary discussions of how the impacts of grid interconnections on air pollutant emissions (and, subsequently, the impacts of those emissions) might be calculated, provide some rough example calculations for specific grid interconnection scenarios in Northeast Asia, and discuss some of the ways in which the avoided air pollution benefits of a Northeast Asia grid interconnection might be maximized.

In general, this section attempts to include discussions of the air pollution impacts of all of the parts of the full electric fuel cycle that might occur in any (or all) of the interconnected countries. In practice, however, the major air pollutant emissions changes due to the installation of grid interconnections are likely to be from power generation. As a consequence, emissions from other parts of the fuel cycle, including air pollutant impacts of line construction (including diesel exhaust and fugitive dust), are mentioned, but not treated in any detail, as these impacts are relatively transient and of short duration, and thus typically limited, in any given location. The focus below is therefore on air pollutant impacts of power system operation with and without a grid interconnection between nations.

## *2.2. Local Air Pollutant Impacts*

Air pollutants with local impacts that are emitted from various parts of electricity system fuel cycles include the following major species and categories:

- **Carbon monoxide**, or CO, which results from incomplete combustion of carbon-based fuels. Carbon monoxide is typically a relatively minor component of emission from electricity generation facilities that are properly operated, as most electricity generation facilities burn fuels under conditions of excess oxygen. Vehicle exhaust, on the other hand, including exhaust of transportation and heavy construction equipment involved in power line construction, is often relatively rich in CO.

- **Sulfur dioxide** ($SO_2$), which is typically the major species in the broader class of sulfur oxides ($SO_x$, in general). $SO_x$ are formed when the sulfur in fuel is oxidized during the combustion process. As a consequence, $SO_x$ emissions, if not controlled, may be substantial for power plants fired with relatively sulfur-rich fuels such as coal and heavy fuel oil. Some grades of diesel fuel also include significant concentrations of sulfur compounds, and as a consequence the emissions from trucks and other heavy equipment can be a source of $SO_x$.

- **Nitrogen oxides** ($NO_x$), principally NO and $NO_2$. $NO_x$ species are formed both by oxidation of nitrogen compounds present in fuel and by high-temperature oxidation of the molecular nitrogen that is the main constituent of air. As a consequence, combustion of all fuels, even fuels with no nitrogen component, can yield $NO_x$. Higher combustion temperatures (which generally promote more complete combustion) tend to <u>increase</u> $NO_x$ formation, as more $N_2$ from the air is oxidized.

- **Volatile organic compounds**, or VOCs, sometimes referred to as "Hydrocarbons" or "Non-Methane VOCs". The many different species in this class of compounds results from incomplete combustion of organic materials in carbon-based fuels. Fuels that are composed of larger and more complex organic molecules will generally produce more complex and more different species of VOCs, but combustion conditions play a critical role in determining both the types and amount of VOCs emitted from a given device. Again, typically, power plants that are well-run and in good condition will emit relatively low concentrations of VOCs, as most VOCs in combustion gases will be fully oxidized to $CO_2$, but poor or poorly controlled power plant boilers, and many vehicle engines, can emit substantial concentrations of VOCs. In addition to VOC emissions as products of incomplete combustion of carbon-based fuels, VOCs are also emitted from evaporation or leakage of fuels and lubricants from fuel production, transport, and storage facilities (for example, oil wells, tanker ships and trucks, and petroleum refineries) or from fuel-using devices (such as automobile gas tanks and engine crankcases). Sub-classes of VOCs that are often of particular include PAH (polycyclic aromatic hydrocarbons), POM (Polycyclic Organic Molecules) and other VOC species whose molecular structure gives them biological activity of particular importance.

- **Particulate matter**, also referred to as "particulates", "dust", or "smoke", and sometimes abbreviated TSP for Total Suspended Particulates. This category includes a variety of different compounds—including inert materials such as ash, organic molecules, unburned fuel, and particles of sulfate—that form microscopic and larger particles. Particulate emissions are emitted by power plants (particularly those burning coal and heavier oil fuels), by heavy equipment using diesel fuel. Fugitive emissions of particulate matter (such as wind-blown dust) related to energy facilities can come from coal storage piles, coal mining operations, or ash storage of disposal sites. Particulate matter (PM) is often divided into categories based on the average size of the particles. "$PM_{10}$", denoting the fraction of particulate matter with particle diameter of 10 microns ($10 \times 10^{-6}$ meters) or less, and "$PM_{2.5}$", denoting the fraction of particulate matter with particle diameter of 2.5 microns or less. The $PM_{10}$ and $PM_{2.5}$ fractions are important because they penetrate further into the respiratory system than larger PM particles.

- **Heavy metals** are often associated with the combustion of coal and some heavy oils, and are often emitted in association with particulate matter. Heavy metals of concern for emissions from energy facilities include lead, arsenic, boron, cadmium, chromium, mercury, nickel, and zinc.

- **Radioactive** emissions to the atmosphere stem primarily from the operation, maintenance, and decommissioning of nuclear power plants and the production, refining, storage, and disposal of the materials that fuel them, but can also be released in very small quantities during activities such as coal mining and combustion. Emissions during operation of nuclear power plants can be direct emissions (either routine or accidental) from the reactor itself, emissions of "activation products" (such as metals that are part of the reactor that have been irradiated by operation of the reactor and have become radioactive themselves), and emissions from low-level and high-level wastes in storage. Emissions of radioactive materials are typically measured in Curies, abbreviated Ci, which specifies the number of particles emitted per second from a radioactive material. Routine emissions from nuclear reactor and nuclear fuel chain operations are typically relatively minor. Accidents at nuclear facilities, however, can release radioactive materials to the atmosphere ranging in amount from modest to highly significant, with the Chernobyl incident the prime example of the latter. Radioactive gas emissions can include the isotopes **Carbon-14**, **Iodine-131 (Elemental)**, **Iodine-131 (Nonelemental)**[11], **Noble Gases** (including Krypton and Xenon), **Radon**, and **Tritium** (H-3).

#### 2.2.1. Potential local impacts

The local air pollution impacts of power plants run to provide electricity for a line, and the local air pollution benefits of not operating certain power plants due to the availability of electricity from a grid interconnection, will be a function of the type of power plant used or avoided, its proximity to populations or ecosystems that might be affected, the types of control equipment used on the plant, and the species of pollutant emitted. Another key variable is atmospheric conditions, including the presence of other pollutants. Many species of air pollutants react with each other and with other molecules in the atmosphere to form compounds of greater concern. Photochemical smog is an example of a pollution problem caused by the presence of several different pollutant species. The summaries that follow provide very brief reviews of some of the key human health impacts of each pollutant species[12].

- **Carbon monoxide** is a local air pollutant with respiratory impacts, and contributes both directly (as it oxidizes to $CO_2$) and indirectly to the increase in greenhouse gas concentrations in the atmosphere (see below). CO's respiratory impacts on human and animal health stem primarily from the ability of the CO molecule to bind to hemoglobin, the oxygen-carrying molecule in blood, and thereby reduce the supply of oxygen to the brain in human and other tissues. Since carbon monoxide binds more readily to hemoglobin than oxygen, even relatively low concentrations of CO in the air can

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[11] That is, iodine emitted as a compound with other elements.

[12] Some of the discussions of pollutant impacts presented here and in other parts of this report are taken or adapted from M. Lazarus, D. Von Hippel et al (1995), A Guide to Environmental Analysis for Energy Planners. Stockholm Environment Institute--Boston, December, 1995. Available as

lead to carbon monoxide poisoning, which is characterized by headaches, dizziness, and nausea in mild cases, and loss of consciousness and death in acute cases.

- **Sulfur oxides** can react with water and oxygen in the atmosphere to yield sulfuric acid, one of the major components of acid rain (see below). $SO_2$ itself can damage plants, with acute exposure to the gas causing death of part or all of a plant, and chronic exposure, though the threshold at which plants are affected varies widely among different plant species. In humans, exposure to $SO_2$ at high levels (above about 5 parts per million, or ppm; the average concentration in urban air in the U.S. is about 0.2 ppm) causes respiratory problems, though exposure to significantly lower doses can sometimes exacerbate existing respiratory problems in sensitive individuals. In developing countries and other areas where coal is used as a home heating and/or cooking fuel, $SO_x$ can be an important health hazard as an indoor air pollutant.
- **Nitrogen oxides** can contribute to environmental problem in several ways. Short-term exposure to elevated $NO_2$ concentrations (0.2 to 0.5 ppm) can cause respiratory symptoms among asthmatics. Indoor fuel combustion, particularly from gas stoves or traditional fuel use, can lead to elevated indoor levels which have been associated with increased respiratory illness and reduced disease resistance among children. Nitrogen oxides contribute to the formation of tropospheric ozone and nitrate aerosols (fine particulates), which are major air pollutants in themselves. Atmospheric emissions of $NO_x$ also contribute to the formation of the photochemical smog prevalent in many urban areas, and thus have a general detrimental effect on the respiratory health of humans and other animals, as well as on visibility. In high concentrations, $NO_x$ can injure plants, though the required concentrations usually only exist near a large (and uncontrolled) point source of the pollutant. The major hazard to plants from nitrogen oxide emissions may be through the effect of $NO_x$ on ozone formation. Atmospheric nitrogen oxides in high concentrations cause respiratory system damage in animals and humans, and even in relatively low concentrations they can cause breathing difficulties and increase the likelihood of respiratory infections, especially in asthmatics and other individuals with pre-existing respiratory problems.
- Individual **VOC** (or hydrocarbon) species exhibit various degrees of toxicity in different animal species. Many hydrocarbons are also carcinogenic (promote the growth of cancers) and/or promote genetic mutations that can lead to birth defects. Hydrocarbons can also be bioconcentrated, leading to amplified toxic effects in animals at the top of the food chain. As a class, hydrocarbons contribute to the production of photochemical smog and of ground level ozone, which are dangerous to human health due to their effects on the respiratory system. High ozone levels also damage crops, forests, and wildlife.
- Anyone who has traveled down a dusty road can appreciate the effect of **particulate** emissions on the human upper respiratory system (nose, throat), but smaller particles can also penetrate deep into the lungs, where they can aggravate existing respiratory problems and increase the susceptibility to colds and other diseases. Particulates can also serve as carriers for other substances, including carcinogens and toxic metals, and in so doing can increase the length of time these substances remain in the body. Particulate matter in the air impairs visibility and views, and particulate matter settling on buildings, clothes, and other humans may increase cleaning costs or damage materials. Particulate matter is an important indoor air pollutant in areas where open or poorly-vented household cooking and heating equipment is used, particularly with "smoky" fuels such as wet biomass, crop and animal residues, and low-grade coals. Particulate matter can settle on plants, reducing plant growth by reducing plants' uptake of light and carbon dioxide. Coal dust is of special

concern as a particulate pollutant due to the presence in the coal particles of heavy metals and other trace constituents of coal. It is inhalation of coal dust that causes the "black lung" disease frequently seen among coal miners, particularly in mining operations where mine ventilation and dust masks are inadequate. A subset of particulate emissions that has been a topic of considerable research in recent years is "**black carbon**", which, in addition to its local health and other impacts, appears to have implications for regional climate, as described in section 2.3.3 below.

- The impacts of **metals** on the environment and on human health vary with the metal element (and sometimes compound) emitted. As most metals are emitted as part of particulate matter, the lifetime of metals in the atmosphere is equal to that of the particles to which they are attached, which depends on the particle size (smaller particles remain in the atmosphere longer) and prevailing meteorological conditions. Some metals are plant nutrients in low concentrations, but toxic in higher concentrations. *Lead*, for example, is well known to cause "loss of appetite, weakness, awkwardness, apathy, and miscarriage" [13], and affect many organs and systems within the body, including the central and peripheral nervous systems, the kidneys, and the blood synthesis and circulation systems. Lead also has impacts on wild and domesticated animal populations. Arsenic is a well-known poison. Symptoms of chronic (exposure to lower concentrations over a longer term) arsenic poisoning include fatigue, peripheral nervous system problems; and blood problems. *Arsenic* has also been implicated as a carcinogen (that is, in promoting the growth of cancers) and in causing birth defects. The environmental effects of arsenic are enhanced by its tendency to accumulate in plant and animal tissues. *Boron*, a nutrient at low concentrations, but acute effects of boron compounds on the health of humans and other animals include damage to the central nervous and respiratory systems, as well as to the kidneys. *Cadmium's* primary health impacts for both acute and chronic cadmium exposures are on the kidneys, the respiratory system, and on bone formation. Cadmium is also easily bioconcentrated. The symptoms of *Mercury* poisoning in humans include "headache, fatigue, irritability, tremors, and other nervous disorders"[14]. These neurological symptoms are the origin of the phrase "mad as a hatter", as hat makers routinely used mercury in their trade. Mercury is retained in the bodies of animals, and is concentrated by the food chain. The most well publicized type of this bioconcentration leads to high concentrations of mercury and mercury compounds in large food and sports fish such as tuna and swordfish. Large predatory birds have also been adversely affected by the mercury in their food, which may be of particular concern for bird populations in Northeast Asia.
- The effects of **radioactive** emissions on human health have been documented by the populations exposed following the explosion of the nuclear bombs over Hiroshima and Nagasaki in Japan, and by the Chenobyl reactor accident in the Ukraine. These health effects include acute effects such as radiation sickness (characterized by nausea, damage to bone marrow, and other symptoms), and chronic effects such as increases in cancer rates, genetic effects, prenatal problems, effects on fertility, shortening of life, and cataracts of the eye. It should be noted that the amount of radioactivity to which the public is exposed during routine operation of nuclear plants is generally not thought sufficient to contribute to these problems. Radioactive emissions settling on agricultural areas can be carried to a wider population through farm products such as milk. Animals and plants exposed to radiation can also suffer short and long-term damage.

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[13] Ehrlich, P.R, A.H. Ehrlich, and J.P. Holdren (1977), ECOSCIENCE. W.H. Freeman and Co., San Francisco, California, USA. Page 568.

[14] P.R. Ehrlich et al, (ibid, p. 572).

### 2.2.2. Emissions location as a important element

Some possible configurations of grid interconnections in Northeast Asia include trade-offs of fossil-fueled generation in different locations. The net local air pollution benefits (or impacts) of a grid interconnection will in those cases depend upon where the power plants run more and those that run less are located, as well as upon the types of power plants (and their air pollution control equipment) in each case. For example, an interconnection that results in the extended use of coal-fired power plants in remote areas of the Russian Far East but avoids coal-fired generation in more heavily populated China, the ROK, or the DPRK may result in a net positive impact on human health, although such factors as topography, local weather conditions (and other local pollutant emissions), and impacts on plants, (non-human) animals, and ecosystems must also be taken into account. As noted by Dr. David Streets, the displacement of power generation from typically urban power plants in China, Mongolia, and the DPRK, to remote areas of the RFE may result in considerably reduced human exposure to air pollution hazards[15].

### 2.2.3. Potential "fuel-switching" benefits

A Northeast Asia grid interconnection that results in improved availability of electricity in specific areas may have significant impacts on local and indoor air pollution. To the extent that, for example, electricity from a grid interconnection can offset the use of relatively poor quality or polluting fuels, such as the use of low-quality coals or biomass for cooking and heating, grid interconnection may have provide significant local health benefits. The regions most likely to benefit from this type of fuel switching are rural areas of the DPRK and, to a probably lesser extent, some rural areas of China. A paper entitled "The Potential Impact of the Inter-state Electric Ties in North East Asia on Environment", by the DPRK Delegation to the Third Grid Workshop, underscores this potential benefit of grid interconnections[16].

## *2.3. Regional Air Pollutant Impacts*

Although some photochemical smog and other air pollution impacts can, at times, be sufficiently widespread as to be nearly regional in nature (some air pollution problems in the Pearl River Delta and nearby areas South China, for example, have at times covered a large territory), arguably the major regional air pollution impact is acid precipitation, sometimes called "acid rain". Depending on the way that a grid interconnection is operated, net regional emissions of acid gases could be reduced or displaced. Brief descriptions of some of the issues associated with the emissions of air pollutant precursors to acid precipitation are provided below[17].

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[15] D. Streets (2003), "Environmental benefits of electricity grid interconnections in Northeast Asia". Energy, volume 28 (2003), pages 789–807.

[16] This paper is available as http://www.nautilus.org/energy/grid/2003Workshop/K_DPRK_2_PPR.pdf.

[17] Relevant discussions of these issues can also be found in D.F. Von Hippel (1996), Technological Alternatives to Reduce Acid Gas and Related Emissions from Energy-Sector Activities in Northeast Asia, Nautilus Institute Report prepared for the ESENA project, November, 1996 (http://www.nautilus.org/papers/energy/dvhtech.html), from which some of the discussions in this paper are adapted; Carmichael, G., and Arndt, R (1996), Baseline Assessment of Acid Rain in Northeast Asia (http://www.nautilus.org/papers/energy/carmichaelESENAY1.html); and D. G. Streets (1997), Energy and Acid Rain Projections for Northeast Asia (http://www.nautilus.org/papers/energy/streetsESENAY1.html), all of which are Nautilus Institute Reports prepared for the Energy, Security and Environment in Northeast Asia (ESENA) Project.

### 2.3.1. Acid deposition

Acid deposition results when nitrogen and sulfur oxides ("$NO_x$" and "$SO_x$") react in the atmosphere with oxygen and water droplets to form nitric and sulfuric acids ($HNO_3$ and $H_2SO_4$). As the water droplets condense, they fall as rain, snow, or fog, hence the common name "Acid Rain". We should note that while acid rain is the most frequently discussed pathway for these compounds to return to earth, nitrates and sulfate ions[18] ($NO_3^-$ and $SO_4^{2-}$) also can combine with positive ions or adhere to the surface of particles in the atmosphere, sometimes falling to earth in a dry form ("dry deposition"). $SO_x$ and $NO_x$ can also directly adhere to soil or plant surfaces, eventually reacting with water and oxygen to form acids. As a consequence, the terms "Acid Rain" and "Acid Precipitation" are somewhat incomplete—though more common—terms for the broader phenomenon of acid deposition, the term we use most frequently here.

The standard measure of acidity is the *pH* scale. pH is equal to the base-10 logarithm of the concentration of hydrogen ions ($H^+$), and is given on a scale of 0 to 14, with low pHs being indicative of highly acid solutions (e.g. vinegar), and high pH's being indicative of highly alkaline (or basic) solutions (such as lye). Neutral pH, the pH of distilled water, is 7.0, and physiological pHs, that is, the pHs most commonly found in plant and animal cells, are typically (but not always) between 6 and 8. In the atmosphere, water reacts with $CO_2$ to form carbonic acid ($H_2CO_3$), a weak acid, and as a consequence the pH of rain and snow in the absence of all pollutants would be about 5.6. Precipitation with a pH lower than this level is considered acid precipitation. Remember that because pH is measured on a logarithmic scale, small changes in pH can mean relatively large changes in acidity. Precipitation with a pH of 4, for example, is 10 times as acid as rain of pH 5.

The effects of acid rain vary considerably with the vegetation, soil types, and weather conditions in a given area. Under some conditions, the addition of sulfate and nitrate to the soil helps replace lost nutrients, and aids plant growth. In other instances, however, acid deposition can cause lakes and streams to become acid, damage trees and other plants, damage man-made structures, and help to mobilize toxic compounds naturally present in soil and rocks. The countries of Northeast Asia have already begun to experience some important impacts of acid rain. Forest health in some areas of the Koreas, China, and Japan has already revealed evidence of degradation that points to acid rain[19]. Man-made materials such as zinc-plated steel have drastically shorter-than-normal lifetimes in south China, and irreplaceable cultural landmarks made of limestone and other substances are being degraded at an accelerating rate[20].

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[18] Ions are electrically charged elements of molecules. Negatively charged elements or molecules (like the sulfate and nitrate ions) are called anions, and positively charged entities are called cations. Anions and cations combine to neutralize each others' charge and yield salts, such as the common table salt, NaCl, which is made up of a positively-charged sodium atom ($Na^+$) and a negatively-charge chloride ion ($Cl^-$).

[19] Hayes, P., and L. Zarsky, "Acid Rain in a Regional Context", in Science and Technology Policy Institute and the United Nations University's Joint Seminar on "The Role of Science and Technology in Promoting Environmentally Sustainable Development. Science and Technology Policy Institute and The United Nations University, Seoul, Republic of Korea, June, 1995.

[20] Hamburger, J., China's Energy and Environment in the Roaring Nineties: A Policy Primer. Prepared for the United States Environmental Protection Agency and the United States Department of Energy by Pacific Northwest Laboratories Advanced International Studies Unit, Washington D.C., USA. 1995.

Acid rain has been implicated in the death of fish and other aquatic life in otherwise pristine lakes in the northeast United States, southeast Canada, and Scandinavia. Lakes and soils with minimal *buffering capacity* (the ability to maintain pH in response to the addition of acids), such as many of those found in these areas, are particularly susceptible to acid rain. The lowered pHs in some North American and Scandinavian lakes has resulted in loss of and/or shifts in species composition of the phytoplankton (including algae) that are the base of the aquatic food chain, and damage—direct and indirect—to aquatic invertebrates (such as insects and small crustaceans), amphibians, and fish. The gradual die-off of forests in Germany, Sweden, and other areas has also been attributed to the effects of acid deposition. Plants are affected by acid rain in several ways, including direct erosion of cellular structures in leaves, interference with cell processes and the uptake of gases (including $CO_2$) from the atmosphere, alteration of soil chemistry and the activity of bacteria and other microorganisms in soil, interference with plant reproduction, and weakening of plants' susceptibility to disease and pests. Buildings and other structures, including many ancient cultural landmarks, are being degraded by acid rain, particularly those structures made of minerals, such as limestone, that are more soluble in more acidic solutions. In soils with limited buffering capacity, the acidified water flowing through the soil can dissolve and mobilize potentially toxic minerals, such as aluminum, leading to elevated concentrations in streams and lakes. A nutrient in small quantities, aluminum can become toxic to fish and other organisms at the higher concentrations found in acidified watersheds[21].

While natural sources account for a significant, though uncertain, fraction of the atmospheric sulfur and nitrogen oxides that are the precursors of acid deposition, human sources appear to be the major cause of recent declining trends in the pH of rainfall. While some industrial sources of emissions, particularly the smelting of metal, are important sources of sulfur oxides, the energy sector accounts for a large fraction of these emissions. As noted above, sulfur oxides are produced during combustion of coal, which contains varying amounts (about 0.5 to 5 or more percent) of sulfur, and during combustion of fuel oil, particularly the heavier grades. These fuels are most commonly used in large industrial facilities and in electric power generation. Nitrogen oxides are produced at varying rates by all types of fossil and biomass fuel combustion; the nitrogen in the $NO_x$ produced during combustion is derived both from nitrogen in the fuel and from the molecular nitrogen ($N_2$) that makes up nearly four-fifths of the air we breathe. Gasoline-powered autos and trucks are major emitters of $NO_x$.

Though acid deposition <u>can</u> be a local phenomenon, particularly in urban areas and in areas near a large point source of emissions, the extent to which acid gases are carried by prevailing weather patterns makes acid rain a truly <u>regional</u> issue, one that frequently crosses national boundaries. For example, many of the acidified lakes in Eastern North America are hundreds of kilometers from major sources of emissions. Likewise, emissions from as far away as the United Kingdom have contributed to acid rain and forest decline in Scandinavia. Automobile use in Southern California is probably a major contributor to low-pH rain and snow in the Colorado Rocky Mountains, well over 1000 kilometers away. The long-term RAINS-Asia project, which has included collaborative and fairly detailed modeling of current and future emissions of sulfur oxide emissions—and more recently nitrogen oxide emissions, for most of

[21] A watershed is the area around a body of water that catches the rain and snow that feed into it.

the countries of Asia, provides an excellent resource for studies of the impacts of energy system changes on acid precipitation in Northeast Asia[22].

A paper by Prof. Zhu Fahua prepared for the Third Grid Workshop and entitled "Environmental Impacts and Benefits of Regional Power Grid Interconnections for China", provides a review of the air pollution impacts, including local and regional (acid gas) emissions, of thermal power plants in use in China. Prof. Zhu's paper also estimates the potentially significant reductions in local and regional air pollutants that might accrue from substituting hydro-based imported power for local thermal generation in Northeast China[23].

#### 2.3.2. Description of issues associated with transport of pollutants and recipient areas

Indications from the current pattern of $SO_x$ transport in Northeast Asia are that while virtually all of the sulfur oxides falling to earth in China originate in China, emissions from other countries constitute from 15 percent (the ROK) to over 60 percent (DPRK) of the total deposition in some of the other countries of the region[24]. A review of the soil types in the region most subject to acidification shows that key agricultural areas in Southern and Eastern China, in North and South Korea, and in Japan are at risk[25].

The potential huge growth in regional emissions, coupled with the regional nature of atmospheric transport of acid gases and the sensitivity of key ecosystems to acidification, makes acid rain in Northeast Asia a problem that a) must be responded to forcefully and soon, and b) must be addressed at the regional level, as well as nationally and locally. The potential of transmission interconnections to displace from one location to another or (in some configurations and depending on which plants are used to feed electricity into the line) to reduce overall regional emissions may be one element of an overall acid gas emissions reduction strategy for Northeast Asia. What this suggests is that the evaluation of the net changes due to a transmission interconnection in emissions of sulfur oxides, nitrogen oxides, and the several other species of pollutants that interact with those gases should be assessed for each interconnection scheme considered. Such assessments must take into account, at least crudely, the locations where net emissions will change, the seasonal meteorology of and timing of emissions changes, the pattern of long-range transport of pollutants from where they are emitted (or avoided) and the sensitivity of the areas where deposition from the emissions will occur. This sort of modeling is not at all easy, significant air pollution modeling capabilities are available in several of the countries of Northeast Asia, and there are results from regional models, such as the "RAINS-Asia" model prepared by the International Institute for Applied Systems Analysis and a

[22] See http://www.iiasa.ac.at/Research/TAP/rains_asia/docs/home_text.html for an introduction to the RAINS-Asia project and simulation software.

[23] Please see http://www.nautilus.org/energy/grid/2003Workshop/Environmental%20Impacts_Zhu_final2.pdf.

[24] Hayes and Zarsky, ibid.

[25] The sensitivity of soils to acidification does not, of course, relay the complete picture of where acid precipitation could cause the most damage. Vegetation types, topography, and land use also play important roles. For example, areas with soil types that are most sensitive to acidification may not (and often do not) have vegetation that is similarly at risk.

consortium of investigators, that could possibly be parameterized to assist in rough assessments of the impact of grid interconnections on acid deposition[26].

### 2.3.3. Impacts of "black carbon" emissions on regional climate

Recent research has indicated that the emissions of "**black carbon**" (soot) particulates, mostly emitted from coal and biofuels combustion—largely in rural areas, may, in addition to their impacts as indoor and local air pollutants, be causing changes in regional and even global climate[27]. Black carbon particles in the atmosphere absorb sunlight and "heat the air, alter regional atmospheric stability and vertical motions, and affect the large-scale circulation and hydrologic cycle with significant regional climate effects"[28]. Higher recent incidence of floods in South China, and drought in North China, as well as moderate cooling in China and India during a period when most of the rest of world has experience warming, may, modeling results suggest, be impacts of regional black carbon emissions. To the extent that they can assist in reducing black-carbon-emitting use of coal and biofuels, regional grid interconnections may be able to claim additional regional environmental benefits.

## *2.4. Global Air Pollution Impacts*

Grid interconnections in Northeast Asia, depending on how they are designed and operated, may offer significant benefits in terms of avoided emissions of "global" air pollutants. Two possible types of emissions can be considered here. The first are emissions of "greenhouse gases" that contribute to climate change. The second are emissions of gases and particles that recent research suggests may be transported considerable distances from Northeast Asia, even across the Pacific. Each of these classes of global air pollution impacts are described briefly below, and discussions are provided as to how grid interconnections might affect emissions that cause these classes of impacts.

### 2.4.1. Greenhouse gas emissions

Global warming", "climate change", and the "greenhouse effect" are common expressions used to describe the threat to human and natural systems resulting from continued emissions of heat-trapping or "greenhouse" gases (GHGs) from human activities. These emissions are changing the composition of the atmosphere at an unprecedented rate. Although

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[26] See, for example, http://www.iiasa.ac.at/Research/TAP/rains_asia/docs/rains.asia.html, which provides access to some RAINS-Asia-related information and results. Papers by D. Streets referenced above include results based on RAIN-Asia research, and a substantial volume of additional literature documenting research from the project is also available. As an example of the type of information that would be required to rigorously evaluate the impact of grid interconnections on regional acid deposition, methods for preparing inventories of air pollutant emissions for use in transboundary air pollution modeling are provided in D. Von Hippel and H. Vallack (2000), Manual for Preparation of Emissions Inventories for Use in Modeling of Transboundary Air Pollution, prepared as a part of the UNDP/UN DESA Subregional Project RAS/92/461: "Energy, Coal Combustion and Atmospheric Pollution in Northern Asia", May, 2000.

[27] See, for example, David G. Streets, Shalini Gupta, Stephanie T. Waldhoff, Michael Q. Wang, Tami C. Bond and Bo Yiyun (2001), "Black carbon emissions in China", Atmospheric Environment, Volume 35, Issue 25, September 2001, Pages 4281-4296; and Surabi Menon, James Hansen, Larissa Nazarenko, and Yunfeng Luo (2002), "Climate Effects of Black Carbon Aerosols in China and India", Science, Vol 297 27 September, 2002.

[28] Quote from Menon *et al* article referenced above.

the complexity of the global climate system makes it difficult to accurately predict the impacts of these changes, the evidence from modeling studies as of the mid-1990s, as interpreted by the world's leading scientists assembled by the Intergovernmental Panel on Climate Change (IPCC), indicates that global mean temperature will increase by 1.5 to 4.5º C with a doubling of carbon dioxide concentrations, relative to pre-industrial levels[29]. Given current trends in emissions of greenhouse gasses, this doubling—with its attendant increase in global temperatures, would likely happen in the middle of the 21st century. For reference, a global increase of 2º C from today's levels would yield global average temperatures exceeding any the earth has experienced in the last 10,000 years, and an increase of 5º C would exceed anything experienced in the last 3,000,000 years. Moreover, it is not simply the magnitude of the potential climate change, but the *rate* of this change that poses serious risks for human and ecosystem adaptation, with potentially large environmental and socioeconomic consequences.

The essence of the greenhouse effect is that particular trace or "greenhouse" gases in the atmosphere absorb some of the outgoing radiation on its way to space from the surface of the earth. These gases, principally water vapor ($H_20$), carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), and ozone ($O_3$), together act as a transparent atmospheric "blanket" that allows sunlight to warm the earth but keeps infra-red radiation (heat) from leaving the earth and radiating out to space

Without this atmospheric "blanket" of trace gases, the equilibrium surface temperature of the earth would be approximately 33° C cooler than today's levels, averaging -18ºC rather than +15ºC, and making the earth too cold to be habitable. It is this blanketing effect of the atmosphere that is referred to as the greenhouse effect. A greenhouse is a useful analogy; the atmosphere behaves somewhat like the glass pane of a greenhouse, letting in visible or short-wave radiation, but impeding somewhat the exit of thermal energy, thereby increasing the equilibrium temperature inside the greenhouse.

The present concern with global warming does not center on the *natural* greenhouse effect of the atmosphere on global equilibrium temperature and climate. Rather, it arises from the potential *additional* global warming that may occur due to the rapidly increasing concentrations of heat-trapping greenhouse gases. Measurements taken at remote locations around the globe have revealed that current concentrations of greenhouse gases in the atmosphere substantially exceed their pre-industrial levels. The primary human activities that are responsible for this growth in atmospheric concentrations of these gases are the combustion of fossil fuels and the reduction of carbon stored in biomass through conversion of forests and other natural land types to settlements, agricultural land, and other uses.

The combustion of all carbon-based fuels, including coal, oil, natural gas, and biomass, release carbon dioxide ($CO_2$) and other "greenhouse gases" to the atmosphere. Over the past century, emissions of greenhouse gases from a combination of fossil fuel use, deforestation, and other sources have increased the effective "thickness" of the atmospheric blanket by increasing the concentration of greenhouse gases (or GHGs) in the *troposphere*, or lower part of the

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[29] Intergovernmental Panel on Climate Change (1992), *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment*. J. T. Houghton, B. A. Callander and S. K. Varney, eds. Cambridge, U.K.: Cambridge University Press, p.5.

atmosphere (ground level to about 10-12 km). It is this "thicker blanket" that is thought to be triggering changes in the global climate.

Other major "direct" greenhouse gases emitted by combustion activities and other fuel cycle activities are methane ($CH_4$), and nitrous oxide ($N_2O$). Both of these gases have substantial non-energy sector sources. Chlorofluorcarbons (CFCs), which are man-made chemicals used as refrigerants, as fire retardants, and for other purposes, are another major class of direct greenhouse gases, but their direct emissions from the energy sector are not significant. A number of gases may also indirectly affect global climate. Carbon monoxide (CO), nitrogen oxides ($NO_x$), non-methane hydrocarbons (NMHC), and methane are all thought to contribute indirectly to global warming by affecting the atmospheric concentration of other greenhouse gases (such as tropospheric and stratospheric ozone)[30]. Because of incomplete understanding of the chemical processes involved, these indirect contributions to warming are more uncertain than the contributions of the direct greenhouse gases ($CO_2$, $CH_4$, $N_2O$, CFCs).

Another potential source of greenhouse gases that should be investigated in any grid interconnection scheme that is likely to involve construction of new hydroelectric facilities are biomass decomposition in areas flooded for hydroelectric reservoirs. In the context of discussions of grid interconnections from Quebec, Canada to the Northeast United States, the following point was made[31].

> "On a large scale and from an environmental point of view, hydroelectric energy development can be an ideal complement to energy needs and parallel commitments to reduce greenhouse gas emissions. The analysis, however must account for the greenhouse gases produced by biomass degradation in reservoirs, and Hydro-Quebec is presently studying this phenomenon."

Assessment studies have shown how climate changes and sea level rise may give rise to a vast array of biological and physical impacts. In many cases, these impacts are local in nature, but may be inherent to many parts of the region and are thus listed here. Particular examples of estimated regional impacts include:

- Changes in temperatures
- Changes in the amount of precipitation
- Changes in the timing of precipitation
- Changes in plant growth rates
- Changes in the severity of storms and floods—and erosion exacerbated by storms and floods—as well as in the timing and amount of water discharged by rivers.
- Changes in forests due to changes in temperature, precipitation, and evaporation.
- Changes in the distribution and prevalence of plant and animal pests and diseases.

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[30] Methane has both direct and indirect effects.

[31] A. Vallée and G. Jean Doucet (1998), "Environmental Implications or international Connections: The New Arena", in IEEE Power Engineering Review, August 1998, "International High-Voltage Grids and Environmental Implications", http://www.geni.org/energy/library/technical_articles/transmission/IntlGridandEnvironment.html.

- Changes in biodiversity and species distribution—all of the changes above have the potential to alter the distribution and range of plant and animal species, including both domesticated crops and livestock and native flora and fauna.
- Changes in ocean temperatures and their effects on ocean productivity, including the productivity of and growth rates of reef ecosystems.
- Changes in sea level rise brought on by the expansion of warmed ocean waters and by the melting of polar ice. Hundreds of meters to many kilometers of shoreline inundation may result from tens of centimeters of sea level rise. Coastal wetlands are especially at risk from increases in the sea level associated with climate change. The changes in climatic variability discussed above—changes in the severity, frequency, and location of tropical storms, for example—will compound the impact of sea level rise, and place coastal ecosystems, infrastructure, and populations even more at risk.

Although the construction and maintenance of transmission lines for grid interconnection will imply modest emissions of greenhouse gases, especially $CO_2$, from fuel burned in transport and construction equipment, the major implications of grid interconnections on climate change will be from emissions related to the generation of electricity. The nations to be interconnected include power plants the burn coal, oil, and natural gas, as well as nuclear and hydroelectric plants. To the extent that plants that burn coal, especially older, inefficient plants, can be displaced by imported electricity generated using (for example) nuclear and hydroelectric energy, the overall regional greenhouse gas emissions will decrease. Other net fuel-cycle emissions or savings, including methane emissions from coal mining, gas and oil extraction, and fuel transport, must also be taken into account when figuring the net impact of grid interconnections on greenhouse gas emissions.

One potential issue of note that is related to the net greenhouse gas emissions benefits (if any) of grid interconnections has to do with options for the financing of grid interconnections. A demonstration that a grid interconnection will lead to substantial net greenhouse gas emissions reductions may allow the project to qualify from partial funding via the Global Environment Facility (GEF) or through Clean Development Mechanisms (CDM). These possibilities are discussed in greater detail in the final section of this paper.

#### 2.4.2. Trans-Pacific air pollution

In recent years, attention has focused on the possibility that particulate and other pollutants from Eurasia are transported by winds to the Western Hemisphere, and in particular to the areas of North America bordering the North Pacific. A summary article on the topic written in 2000 began as follows[32]:

> "The once-pristine air above the North Pacific Ocean is polluted. Pollutants are transported on mid-latitude westerly winds from Eurasia to the Pacific Ocean basin and across to North America. The expected economic expansion around the Pacific Rim and in the rest of the world will deliver even more pollution unless preventative measures are taken. The risk of adverse effects to wildlife, ecosystems, climate, and human health

[32] K. E. Wilkening, L. A. Barrie, and M. Engle (2000), "Trans-Pacific Air Pollution". Science, Volume 290, Number 5489, Issue of 6 Oct 2000, pp. 65-67.

throughout the Pacific region will increase. Even remote areas such as Arctic and alpine environments are threatened. Ocean productivity and the atmospheric energy budget over the North Pacific Ocean could be altered."

News reports based on recent suggest that Trans-Pacific air pollutant transport is widespread in destinations, sources, and the types of pollutants involved[33]. Accurate quantitative estimates of the sources and receptors—and identification of the key species involved in Trans-Pacific air pollution—may be years away, but this global environmental issue bears at least mention in forward-looking environmental assessments in Northeast Asia. Through their impacts on pollutant emissions from electricity generation and other fuel-cycle activities, grid interconnections could influence the types and amounts of pollutants available for Trans-Pacific transport.

### ***2.5. Requirements for Calculation of Impacts***

A brief roster of the types of information and calculations that are likely to be required for the estimation of the air pollutant impacts/benefits of a Northeast Asia grid interconnection is as follows:

- An assessment of which **power plants**, or classes of power plants, in which locations **will run more, and which will run less**, as a result of the grid interconnection, and the amount by which electricity generation at each plant (or class of plant) is increased or decreased. An indication of the seasonality of increased or decreased generation will also likely be necessary. This assessment itself is decidedly non-trivial. Although relatively simple modeling or assumptions may be used to provide a rough estimate of which plants might be affected, ultimately a collaborative modeling effort that attempts to optimize generation over the several countries potentially involved in an interconnection will be needed. Even a strict economic optimization, however, may not be adequate, as political, financing, and environmental considerations will play a role in determining which plants are affected by an interconnection, and these consideration need to be taken into account in any analysis. The topic of how this type of collaborative modeling could be organized and targeted is taken up again in the final section of this paper ("Next Steps"). In his Study for "Russian Far East–Korea People Democratic Republic–Republic of Korea" Power Grid Connection: Analysis of Current Status, prepared for the Second Grid Workshop, Sergei Podkovalnikov provided an example of an estimate of the calculation of the differences in generation and generation capacity by country, as well as the economic costs and benefits, expected from a Northeast Asia grid interconnection. The sort of information included in Dr. Podkovalnikov's study can be used to estimate net air pollutant impacts grid interconnections.
- An assessment of how the interconnection will affect **other parts of the fuel cycles** that fuel electricity generation, including the impact on the quantity of coal mined (and the location where it is mined), the quantity of gas imported/transported, and the quantity of refined products produced and stored.
- **Emission factors** for power plants implicated in the interconnection. These factors will express the emissions of atmospheric pollutants in mass (or radiological) units per unit fuel

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[33] See, for example, "Trans pacific air pollution is worse than was suspected, says new study", http://www.globaltechnoscan.com/2ndAug-8thAug/trans.htm, visited 4/30/03.

consumed, or per unit of power output. If emission factors are expressed per unit of fuel consumed, then the efficiencies (or "heat rates") of the power plants affected by the interconnection must also be collected. In some instances, heat rates and emission factors may depend on fuel quality or on the degree of loading of the plant, though it may be difficult to take the latter into consideration without very detailed modeling and input data. Some key aspects of fuel quality—most notably fuel heat content, carbon content, and sulfur content—are likely inputs to the determination of emission factors. Table 2-1, taken from a paper by David Streets originally prepared for the First Grid Workshop, provides a sample set of emission factors for power plants (and, in the case of biofuels, residential stoves) using different types of fuels[34]. These emission factors are expressed in terms of mass of emissions per unit of input fuel.

***Table 2-1: Sample Emission Factors for Power Generation and Residential Biofuels Use***

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.

- Emission factors for pollutants associated with **other parts of the electricity fuel chain**. These would include, for example, estimates of the fraction of gas carried that is lost from pipelines or from LNG shipping and receiving facilities (including gas consumed in transit), methane and coal dust emissions from coal mining operations, and emissions from oil refining. Emissions to the atmosphere from fuel storage and waste disposal should also, if possible, be counted. Emissions related to power line construction could also be included here, although, as noted above, these are likely to be relatively small, and of short duration.

For greenhouse gases, the product of changes in electricity consumption (by plant or plant class), and emission factors for each plant, plus any changes in other fuel cycle activities multiplied by the greenhouse gas (especially $CO_2$ and methane) emission factors for those activities, gives a measure of the net impact of an interconnection on climate change. In the case of local and regional air pollutants, however, modeling of the fate of emissions, including atmospheric transport and chemistry, deposition, and health impacts, will be necessary for a fully rigorous assessment of the environmental consequences of net air pollutant emissions or savings

[34] Table is taken from Table 5, page 803 of D. Streets (2003), "Environmental benefits of electricity grid interconnections in Northeast Asia". Energy, volume 28 (2003), pages 789–807. Note that in this table "BC" stands for black carbon emissions, and that the $CO_2$ emissions factor shown for biofuels are not necessarily comparable to emissions from fossil fuels, to the extent that $CO_2$ emitted from biofuels production does not make a net contribution to $carbon_2$ in the atmosphere if the biofuels are grown and harvested on a sustainable basis.

due to a grid interconnection. For an approximate assessment, however, the quantities of air pollutants, a consideration of **where** they are emitted, and an approximate consideration, based on prior modeling, of where the net impacts of changes in emissions are likely to occur, may be sufficient. A key environmental benefit of grid interconnection may be the avoidance or displacement of air pollutant emissions from power plants located near urban or ecologically sensitive areas. Identifying and quantifying these types of benefits require the power plant operation estimates, fuel cycle assessments, emission factors, and impacts analyses noted above.

### *2.6. Example Calculation of Impacts, and Interpretation of Results*

In a paper for the First Northeast Asia Grid Interconnection Workshop, rough estimates were prepared of the costs and benefits of power sharing[35]. For that estimate, two scenarios of grid integration were evaluated:

- **Scenario 1**—A line from the northeastern part of the ROK running along the East Coast of the DPRK and into Northeastern China; and
- **Scenario 2**—A line (or set of lines) connecting the Russian Far East, the ROK, the DPRK (including the Simpo reactor site) and Northeast China.

Figures 2-1 and 2-2, below, illustrate the most basic level of information needed to estimate the emissions impacts of interconnection options, and how those data can be organized to calculate the net emissions impacts of an interconnection. In this case, the net impact of emissions reduction on $SO_x$ and $CO_2$ emissions in each of the countries involved in the interconnection, and in the region as a whole (for Scenario 2), were calculated.

As noted, these estimates are quite basic, and cover only two species of air pollutant emissions from electricity generation, neglecting (for simplicity) emissions from other elements of the fuel cycle.

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[35] D.F. Von Hippel (2001), Estimated Costs and Benefits of Power Grid Interconnections in Northeast Asia. Based on a presentation prepared for the Northeast Asia Grid Interconnection Workshop, Beijing, China, May 14 to 16, 200. Available as http://www.nautilus.org/energy/grid/papers/dvh.pdf.

***Figure 2-1: Inputs to and Results of a Sample Estimate of Emissions Impacts of a Grid Interconnection: ROK to NE China via the DPRK***

| | | |
|---|---|---|
| **Assumptions as to Electricity Production and Consumption in Northeast China** | | |
| Fraction of Electricity Produced from Coal in NE China: | 92% | |
| Fraction of power displaced by power from trans. line that would have been coal-fired: | 100% | |
| Average net efficiency of coal-fired (Thermal) power production in NE China: | 27% | |
| Average carbon content of coal used for power generation in NE China: | 56% | |
| Average net heating value of coal used for power production in NE China: | 18.7 | GJ/te |
| Estimated carbon dioxide emissions reduction per GWh power imports: | 1,464 | tonnes |
| Average sulfur content of coal used for power generation in NE China: | 1.10% | |
| $SO_x$ emission control efficiency for plants fitted with scrubbers in NE China: | 80% | |
| Fraction of coal-fired electricity production displaced by imports that has scrubbers: | 0% | |
| Estimate sulfur dioxide emissions reduction per GWh power imports: | 28.76 | tonnes |
| Assuming that power exported to China is from nuclear plants (and thus no GHG emissions are produced when exported power is generated), | | |
| total annual emissions savings are estimated to be: | 15.0 | million tonnes $CO_2$ |
| and annual $SO_2$ emissions savings of | 295 | thousand tonnes |

*Figure 2-2: Inputs to and Results of a Sample Estimate of Emissions Impacts of a Grid Interconnection: ROK to the Russian Far East and NE China via the DPRK*

**Assumptions as to Electricity Production and Consumption in Northeast China**

| | | |
|---|---|---|
| Fraction of Electricity Produced from Coal in NE China: | 92% | |
| Fraction of power displaced by power from trans. line that would have been coal-fired: | 100% | |
| Average net efficiency of coal-fired (Thermal) power production in NE China: | 27% | |
| Average carbon content of coal used for power generation in NE China: | 56% | |
| Average net heating value of coal used for power production in NE China: | 18.7 | GJ/te |
| Estimated carbon dioxide emissions reduction per GWh power imports: | 1,464 | tonnes |
| Average sulfur content of coal used for power generation in NE China: | 1.10% | |
| $SO_x$ emission control efficiency for plants fitted with scrubbers in NE China: | 80% | |
| Fraction of coal-fired electricity production displaced by imports that has scrubbers: | 0% | |
| Estimate sulfur dioxide emissions reduction per GWh power imports: | 28.76 | tonnes |
| Assuming that power exported to China is from nuclear plants (and thus no GHG emissions are produced when exported power is generated), total annual emissions savings are estimated to be: | 15.0 | million tonnes $CO_2$ |
| and annual $SO_2$ emissions savings of | 295 | thousand tonnes |

**Assumptions as to Electricity Production and Consumption in Russian Far East**

| | | |
|---|---|---|
| Fraction of Electricity Produced from Coal in RFE: | 37% | |
| Fraction of power displaced by power from trans. line that would have been coal-fired: | 100% | |
| Average net efficiency of coal-fired (Thermal) power production in RFE: | 31% | |
| Average carbon dioxide emission factor for lignite coal (US value): | 93.19 | kg/GJ |
| Average net heating value of coal used for power production in RFE: | 15 | GJ/te |
| Estimated carbon dioxide emissions reduction per GWh power imports: | 1,068 | tonnes |
| Average sulfur content of coal used for power generation in RFE: | 0.50% | |
| $SO_x$ emission control efficiency for plants fitted with scrubbers in RFE: | 80% | |
| Fraction of coal-fired electricity production displaced by imports that has scrubbers: | 0% | |
| Estimate sulfur dioxide emissions reduction per GWh power imports: | 14.01 | tonnes |
| Assuming that power exported to RFE is from nuclear plants (and thus no GHG emissions are produced when exported power is generated), total annual emissions savings are estimated to be: | 2.7 | million tonnes $CO_2$ |
| and annual $SO_2$ emissions savings of | 36 | thousand tonnes |

**Assumptions as to Electricity Production and Consumption in the ROK**

| | | |
|---|---|---|
| Fraction of Electricity Produced from Coal in ROK: | 35.1% | |
| Fraction of power displaced by power from trans. line that would have been coal-fired: | 100% | |
| Average net efficiency of coal-fired (Thermal) power production in RFE: | 31.5% | |
| Average carbon dioxide emission factor for bituminous coal (US value): | 88.45 | kg/GJ |
| Average net heating value of coal used for power production in ROK: | 25.4 | GJ/te |
| Estimated carbon dioxide emissions reduction per GWh power imports: | 1,011 | tonnes |
| Average sulfur content of coal used for power generation in ROK: | 1.00% | |
| $SO_x$ emission control efficiency for plants fitted with scrubbers in ROK: | 85% | |
| Fraction of coal-fired electricity production displaced by imports that has scrubbers: | 50% | |
| Estimate sulfur dioxide emissions reduction per GWh power imports: | 9.49 | tonnes |
| Assuming that power exported to RFE is from nuclear plants (and thus no GHG emissions are produced when exported power is generated), total annual emissions savings are estimated to be: | 2.6 | million tonnes $CO_2$ |
| and annual $SO_2$ emissions savings of | 24 | thousand tonnes |

**Summary of Emissions Reduction**

| | Mte $CO_2$ | kte $SO_2$ |
|---|---|---|
| **Emissions Reduction in China** | 15.0 | 295 |
| **Emissions Reduction in RFE** | 2.7 | 36 |
| **Emissions Reduction in ROK** | 2.6 | 24 |
| **TOTAL** | 20.3 | 355.0 |

An example of a study in which the net emissions implied for one partner in an interconnection scheme, in this case the Russian Far East, are calculated is the paper "Environmental Impacts and Benefits of Regional Power Grid Interconnection for the Russian Far East: Generation and Fuel-Supply-Related Impacts", prepared by Sergei Podkovalnikov for the Third Grid Workshop[36]. A similar study, in this case from the point of view of a probable net recipient of power transfers, is done for two scenarios of interconnection in the paper "Environmental Impacts and Benefits of Regional Power Grid Interconnections for the Republic of Korea", prepared by Yoon Jae-young*, Kim Ho-yong, and Park Dong-wook[37].

### ***2.7. Strategies for Maximizing Net Air Pollution Reduction Benefits***

The design and implementation of a grid interconnection represents an opportunity to maximize net air pollution benefits along with economic and other benefits[38]. A number of overall strategies could be considered to maximize the net air pollution benefits from a grid interconnection. These include:

- Making sure that areas sharing power are truly complementary. For example, look for opportunities where the seasonality of power demand in source and recipient nations is as far "out of phase" as possible. Generic examples include situations where the source for winter power flows has low electricity demand in the winter, and the recipient has high demand in the winter, or where the source has high availability of hydroelectric power in the summer, and the recipient has a high demand for electric energy and capacity during the summer.
- Target power flows to locations so that the use of the worst existing power plants (lowest efficiency, highest emission factors) and most polluting new power plants are avoided, particularly emphasizing generation facilities near population centers or sensitive ecosystems (for example). This targeting will help to maximize local and regional, as well as global, air pollution benefits. Actually decommissioning aging, inefficient, and polluting power generation facilities as interconnection electricity becomes available may be a way to help secure long-term emissions savings an interconnection, though practical and political obstacles to such linked decommissioning are not unlikely.
- Make sure that any fossil plants whose use will increase as a result of the interconnection has stringent emission controls, and, if possible, is located far from population centers or sensitive ecosystems.

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[36] Available as http://www.nautilus.org/energy/grid/2003Workshop/Podkovalnikov_final.pdf. This paper also provides estimates of selected air pollutant emission factors for power plants in the RFE.

[37] This paper was also prepared for the Third Grid Workshop, and is available as http://www.nautilus.org/energy/grid/2003Workshop/yoon_paper_final1.pdf. This paper provides a structure for the estimation of the greenhouse gas (GHG) emissions impacts of interconnection options, and focuses on the GHG emissions impacts of scenarios of interconnection. This paper also provides a table showing the "Environmental Impacts by Plant Type for Production of 1GWh of Electricity" in the ROK, which includes emission factors for GHGs, ozone-depleting compounds, acid gases, and emissions that can cause eutrophication.

[38] Of course, in reality, the design and implementation of a grid interconnection in Northeast Asia will require the balancing of many different criteria, including not only economic and environmental attributes, but technical, social, and political attributes as well. As a consequence, working out the most useful grid interconnection scheme will require "optimization", some of it subjective, over many different parameters.

- Look for opportunities (taking into account social and economic situations) to displace inefficient and polluting use of fuels for certain end-uses with electricity from the interconnection. A relatively small amount of power targeted at specific regions may yield very significant results in terms of avoided emissions, indoor air pollution, and attendant health problems.

# 3. Impacts of Grid Interconnection on Water Pollution and Water Quality

## *3.1. Introduction*

To perhaps a greater extent than air pollution impacts, significant water pollution impacts—both benefits and negative impacts—of grid interconnections can come construction and maintenance of power lines, as well as from the from different parts of the electricity generation fuel cycles in the interconnected countries. Many of these impacts are likely to be extremely location-specific, even site- and plant-specific. As a consequence, the discussion below largely only mentions generic impacts that can be investigated more fully when an assessment of water pollution impacts of a specific grid interconnection is needed.

## *3.2. Generic Impacts from Construction and Maintenance of Power Line*

A number of potential impacts on water quality may results from the construction and maintenance of transmission lines and their right-of-ways. These potential impacts include:

- Erosion from soils stripped of vegetation during power line right-of-way clearance and power line construction. Erosion impacts are likely to be of concern particularly in areas where forested hillsides must be logged to create a transmission right of way.
- Erosion from access road construction and, during power line operation, from vehicle traffic on existing and new access roads.
- Impacts of heavy machinery operation in rivers and wetlands on water quality.
- Lubrication oil and fuel leakage and other emissions from heavy machinery used in power lines.
- Accidental spills and other emissions of liquids used in transmission infrastructure, including transformer oils.
- Pollution of run-off and groundwater from herbicide treatment of power-line right-of ways, if such treatments are used.

Each of these classes of emissions and impacts can in turn directly affect nearby plants and animals (through toxic responses or changes in the availability or quality of water), or may affect downstream ecosystems and human and animal populations through their impacts on water quality and hydrology. Impacts on water quality may include increasing the quantity of sediments, sediment-borne chemicals, and chemicals from human activities carried in water. Impacts on hydrology can include changing the seasonal rate of flow of water in watersheds, changing the way that water flows through soils, and changing the quality and quantity of groundwater in specific locations.

### *3.3. Specific Impacts of Northeast Asia Grid Interconnections*

Water-pollution related impacts of specific options for grid interconnections in Northeast Asia will be dependant on the ultimate routing of the interconnection considered. One area where under consideration as a power line route linking the Russian Far East and the Korean peninsula includes sensitive wetlands that are home to a wide variety of wildlife. Of the several types of water-related environmental impacts to which wetlands may be subject if a power line is routed through the area, the Public Service Commission of Wisconsin (USA), an area not entirely unlike the Russian Far East in climate, notes the following about the sensitivity of wetland soils to disturbance[39]:

> "Organic soils consist of layers of decomposed plant material. These soils are formed very slowly. If disturbed by filling, digging, or compaction, wetland soils are not easily repaired. Severe soil disturbance may permanently alter wetland hydrology."

### *3.4. Impacts at the Power Plant Level*

As with air pollutant emissions, water pollutant emissions at the power plant level may increase or be avoided by the operation of a grid interconnection. For plants burning fossil fuels, water pollutant emissions may increase or decrease depending on whether the use of a power plant or a class of power plants increases or decreases. The areas in which water pollutant emissions may increase or be avoided include routine emissions from boiler feed water tube cleaning (during plant maintenance), spills and leakage of liquid fuels during handling and from tanks, and leaching of acids, metals, and other potentially toxic materials from coal and coal ash storage piles. These pollutants, if not properly managed or treated, may result in a number of different chronic or acute impacts on ecosystems. All types of thermal power plants, including nuclear power plants, will likely (unless using dry cooling towers are used exclusively) release thermal emissions (warm water) to nearby bodies of water used to cool power plant condensers. These emissions, depending on the size and flow of the heat from the power plant relative to the size and flow of the water to which the heat is released, may have impacts on the aquatic ecosystems in the area, promoting the growth of some aquatic plant and animal species over others, with potential impacts on local fisheries.

An area of potential power-plant-related water quality impacts of particular relevance to Northeast Asia grid interconnections are impacts related to hydroelectric power development. Several possible interconnection schemes would involve the construction of large hydroelectric facilities in the Russian Far East to feed power into the interconnection line. Hydroelectric dam construction may (likely will) result in significant short-term water quality and quantity impacts (including sediment and chemical loads) in the rivers affected by the plant. Hydroelectric operation will change the timing and quality of water available downstream, as well as the sediment load of the river. Areas inundated for reservoirs may contain natural and man-made compounds and materials that, as they decompose or degrade over the years underwater, may leach chemicals into the reservoir, eventually affecting downstream water quality. These types of impacts will be very site- and design-specific, but should be taken into account when assessing the net environmental impact of a grid interconnection.

Another set of sources of water pollutant emissions and water quality impacts may stem from other fuel cycle activities, such as exploration for, extraction of, and transport of petroleum

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[39] Public Service Commission of Wisconsin (1998), PSC Overview Series, Environmental Impacts of Electric Transmission Lines. Available as http://psc.wi.gov/consumer/brochure/document/6010b.pdf.

or coal fuels for power generation. Both routine (such as minor oil losses during transfers from ship to shore terminals) and accidental (such as pipeline "blowouts" or spills of oil or oil products resulting from tanker accidents) emissions of water pollutants may need to be considered in a comprehensive assessment of water pollution impacts. The likelihood is, however, that the sum of these impacts, when averaged over the net impacts of a transmission interconnection on power generation, will be rather modest.

### ***3.5. Preparing Estimates of Water Quality Impacts***

The preparation of some estimates of net additional or avoided emissions of water pollutants (particularly routine emissions from electricity generation or electric fuel cycle activities) resulting from grid interconnections may be relatively straightforward to estimate. For these types of routine emissions, estimates net generation (or avoided generation) by power plant or plant type are needed, as described in the context of estimation of net air pollutant emissions in section 2.5 of this report. Also needed are water pollutant emission factors, which may be derived from plant operating histories, or estimated from international compilations of emission factors (though both may be difficult to find). Estimates of water pollutant emissions of a short-duration (for example, during power line construction) or accidental nature are much harder to estimate. In addition, the ultimate impact on water quality, plants, animals, ecosystems, and humans, of all types of net emissions (or emission savings, including construction-related, routine, and accidental water pollutant emissions) may often require a combination of site- and event-specific qualitative consideration and/or empirical sampling and/or quantitative modeling.

For the purposes of an initial assessment of these emissions and impacts, a thorough consideration of the types of activities that will be increased or avoided by a grid interconnection—together with consideration of where those activities will occur and what types of ecosystems and animal/plant/human populations are present—may have to suffice. In some cases rough calculations can help to identify the range of impacts. For example, given estimates of the area of land inundated by a new hydroelectric reservoir, and knowledge about the vegetation and soil in the area to be inundated, it may be possible to calculate the release of water pollutants, and rough hydrologic modeling may help to indicate downstream water quality impacts.

### ***3.6. Generic Strategies for Maximizing Net Benefit of Transmission Line on Water Pollution/Water Quality***

As the discussion above suggests, it is not entirely straightforward even to determine the net overall impact of a grid interconnection on water quality. Impacts may occur in different parts of the fuel cycle and will occur in different locations—perhaps even locations separated by thousands of kilometers. How to determine what physical and operational configurations of grid interconnections will result in the maximum water quality benefit therefore is likely to become an exercise in subjective judgment in all but the most clear-cut cases. Several overall strategies, however, may be of assistance, including:

- Operate grid interconnections so as to reduce the use of solid and liquid fuels, and thereby to reduce the probability of spills, leakage, and leaching of water pollutants resulting from fuel storage.

- Design and configure the thermal power plants that will feed power into the grid interconnection so that their waste heat either is not emitted directly to water or is emitted to a body of water either isolated from sensitive marine and fresh-water ecosystems or sufficiently well-mixed as to cause a very small temperature perturbation.
- Design any hydroelectric facilities built to feed power into the line to minimize the area to be inundated, and choose the area to be inundated (including consideration of the local geology, soils, and biomass present) so as to minimize likely water pollution impacts.
- Choose power line routings to avoid river and wetland areas as much as possible, including, using taller towers to allow rivers to be spanned rather than using towers in the middle of the river.
- Carry out power line construction in winter when soils are frozen, particularly in wetland areas, so as to minimize disruption and compaction of sensitive soils.
- Use existing roads and right-of-ways whenever possible. Where new roads and right-of-ways are needed, design and construct them with care to avoid erosion and run-off.
- Avoid the use of long-lived herbicides in right-of-way maintenance when easily biodegraded alternatives, or less-invasive non-chemical clearing methods, can be employed. Use heavy machinery as sparingly as possible during power line construction and maintenance.

# 4. Impacts of Interconnection on Generation of Solid and Hazardous Wastes

## *4.1. Introduction*

The third category of pollutant emissions considered in this overview of the environmental impacts of grid interconnections is solid and hazardous wastes. As with air and water pollutants, solid and hazardous wastes can be produced and/or released during power line construction and operation, at the power plant level, or at other points in the fuel cycle. These wastes may be hazardous to health and ecosystems in and of themselves, may present a disposal problem, and, depending on how they are stored and disposed of, may have the potential to create other types of environmental impacts. Leaching of water pollutants from coal ash piles is an example of how solid waste generation can produce water-borne environmental impacts; similarly, dust blown into the air from ash or pulverized coal piles can create an air pollution problem.

## *4.2. Solid and Hazardous Wastes During Power Line Construction and Operation*

The types and extent of solid and hazardous wastes produced during power line construction and operation will vary considerably with the type of power line (and auxiliary equipment such as converter stations and substations) installed, and the local topography and geology. Among the potential types of solid and hazardous wastes that could be produced are:

- Dirt, rock, and other materials removed when footings for power line towers are built, right-of-ways are cleared, access roads are constructed, or foundations for converter stations and substations are prepared.

- Trees and other biomass removed to clear right-of-ways (to the extent that these materials are not used for wood, fiber, or fuel).
- Hazardous materials used in substation transformers, including oils. Particularly in cases where transmission facilities are upgraded or modernized to install the interconnection line, there may be PCBs (Polychlorinated Biphenyls) in older equipment that, if not disposed of appropriately, may cause a variety of effects.

The Agency for Toxic Substances and Disease Registry (ATSDR) of the United States Center for Disease control offers the information about PCBs and their impacts including the following[40]:

- "PCBs entered the air, water, and soil during their manufacture, use, and disposal; from accidental spills and leaks during their transport; and from leaks or fires in products containing PCBs.
- "PCBs can still be released to the environment from hazardous waste sites; illegal or improper disposal of industrial wastes and consumer products; leaks from old electrical transformers containing PCBs; and burning of some wastes in incinerators.
- "PCBs do not readily break down in the environment and thus may remain there for very long periods of time. PCBs can travel long distances in the air and be deposited in areas far away from where they were released. In water, a small amount of PCBs may remain dissolved, but most stick to organic particles and bottom sediments. PCBs also bind strongly to soil.
- PCBs are taken up by small organisms and fish in water. They are also taken up by other animals that eat these aquatic animals as food. PCBs accumulate in fish and marine mammals, reaching levels that may be many thousands of times higher than in water."

Assessment of these highly site-specific construction/demolition-related impacts should be a part of the assessment of an interconnection project. Most of these impacts, however, are likely to be one-time impacts, not ongoing or routine emissions.

### ***4.3. Impacts at the Power Plant Level***

At the power plant level, grid interconnections may result in an increase or decrease in the generation of solid wastes and nuclear wastes, depending, as with air and water pollutants, on which power plants or classes of power plants in which locations (and using which fuels) are run more or less as a result of the interconnection.

Changes in emissions of solid wastes from changes in power plant operations as a result of interconnections will largely be changes in "fly ash" and "bottom ash", plus "scrubber sludge" from emissions control equipment. Ash is an environmental effluent of considerable importance, particularly for large boilers and other types of facilities fueled with solid fuels (especially coal)

[40] ATSDR (2001), ToxFAQs™ for Polychlorinated Biphenyls (PCBs). Available as http://www.atsdr.cdc.gov/tfacts17.html.

and heavy oils[41]. Bottom ash remains in the power plant's boiler after fuel combustion is complete. Fly ash is particulate matter that is captured by pollution-control equipment such as cyclone collectors and fabric filters. Beyond the physical effects of piles of ash on landscapes and on ecosystems, ash from coal and oil combustion contains heavy metals, toxic organic compounds, and other potentially damaging substances that can leach (that is, be dissolved in rainwater and flow out of the pile) out of ash disposal sites and potentially affect ecosystems. If piles of ash are left uncovered, wind can blow smaller ash particles into the air, where their potential effects are those noted for air emissions of particulates. Disposal of ash is also an economic problem, particularly in countries where landfill space is scarce, where ash is defined as a hazardous waste, or where ash must be transported a long distance for disposal.

Scrubber sludge is an effluent of some concern for coal-fired industrial and electricity-generation equipment. A scrubber is a device in which exhaust gasses pass through (typically) a solution of a chemical such as calcium carbonate (limestone) in water. This process "scrubs" sulfur oxides and other components from the exhaust gas stream, and produces a sludge containing calcium sulfate, ash particles, and other chemicals. Some of these compounds can leach from storage areas into the environment, potentially contaminating surface and ground waters.

Nuclear (or radioactive) wastes, including both solid and liquid wastes, are produced routinely during the operation of nuclear power plants. Radioactive solid wastes are of a number of types. Quantities of radioactive wastes can be expressed in terms of radiation loadings (Curies), in terms of waste volume, and in terms of mass. The first category provides a measure of the radiological hazard of the waste, while the latter two give an idea of the storage/disposal volume that would be required per unit energy provided. Low-level wastes contain relatively small amounts of radioactivity, and the risk of human health effects or environmental damage from these wastes are low if the wastes are properly disposed of. Low-level waste disposal facilities are, however, expensive to build and difficult to procure locations for, thus they are of significant concern from a social and economic point of view. High-level radioactive wastes, with large amounts of radioactivity per unit volume, are even more difficult to dispose of in a safe manner. Storage facilities for these wastes must be designed to last up to tens of thousands of years, withstand seismic activity, and keep wastes completely contained far into an uncertain future. The siting of high-level nuclear waste sites has proven extremely difficult in the United States due to concerns over groundwater contamination and other environmental issues, as well as social concerns. The latter include concerns as to the fairness of siting waste facilities in areas, generally with very low population densities, that have had few of the benefits of the electricity generated using the nuclear fuels, and issues of intergenerational equity. Also produced during routine reactor operations is spent reactor fuel. Spent fuel contains uranium, plutonium, and other products of the nuclear reaction, together with the irradiated metal cladding used to contain pellets of uranium oxide (in the light-water reactors used in the US and ROK, at least). A paper by Jungmin Kang prepared for the Third Grid Workshop (“Environmental Impacts and Benefits of Regional Power Grid Interconnections for the Republic of Korea: Potential Impacts on Nuclear Power Generation and Nuclear Waste Production”) discusses in

[41]The combustion of wood and other biomass fuels, to the limited extent that they are used for electricity generation, also yield varying amounts of ash, but their volume per unit energy is generally lower than for coal combustion, and the concentration of potentially toxic substances in the ash is also lower.

more detail nuclear power and nuclear waste issues associated with grid interconnections involving the ROK[42].

### *4.4. Other Potential Fuel Cycle Solid Waste Impacts/Benefits*

Other fuel cycle activities associated with electricity generation also generate solid wastes. These include:

- Wastes from coal mining operations, including such activities as the mining and processing of coal and of oil shale. Inert mining wastes, that is, those materials that are not likely to react with air or precipitation or to be mobile in the environment, may have low toxicity, but piles of inert mining wastes by their physical nature change landscapes and thus the environment, potentially resulting in the displacement of animal species, changes in vegetation (mining wastes are not usually particularly fertile substrates for plant growth) and/or aesthetic impacts. Some mining wastes, however, may react with air or water. Acid mine drainage is often cited as an environmental concern related to coal mining.
- Wastes from oil and gas extraction and refining, including drilling "muds" and spent catalysts and other substances used in refinery operations. These wastes are typically much lower in volume (for example, per unit electricity produced) than coal ash or coal mining wastes.
- Decommissioning (dismantling of power plants after the end of their useful life, including the clean-up and restoration of plant sites) of fossil-fueled power plants produces rubble and metal wastes to be disposed of or recycled.
- Construction of new hydroelectric plants and reservoirs may require the removal or excavation of vast quantities of earth and rock, creating piles of solid waste in the process.
- Nuclear fuel extraction and preparation has its own set of wastes and impacts, including uranium mine and milling tailings, and depleted uranium metal from enrichment activities. These solid wastes must be carefully disposed and monitored to avoid creating a radiological health hazard.
- Nuclear power plants also, at the end of their operating lives, must also be decommissioned. In addition to spent fuel that must be stored indefinitely (or reprocessed, producing high- and low-level wastes that must be stored indefinitely), irradiated power plant components (especially reactor vessel components) must also be carefully dismantled and stored.

### *4.5. Preparing Estimates of Solid and Hazardous Waste Impacts*

Preparing estimates of emissions of solid and hazardous waste emissions is relatively straightforward for solid wastes such as coal ash and for some types of nuclear wastes. For coal ash, an emission factor—typically itself a formula based on the amount of ash in the coal and the fraction of the coal ash remaining in bottom and fly ash—is multiplied by the amount of additional fuel consumed (or fuel use avoided) at a given plant, and the sum of all such estimates over all power plants affected by the grid interconnection is the net coal ash emissions. The ash content of coal can vary widely, ranging from 0.5 percent or less to 30 or more percent. Scrubber sludge production is a function of the sulfur content of the coal used (avoided), the

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[42] Please see http://www.nautilus.org/energy/grid/2003Workshop/papers.html.

efficiency of "scrubbing", the type of process used, and the water content of the product. A similar process can be used to calculate net nuclear spent fuel production, and to estimate, roughly (or as a range) the implied net routine production of low- and high-level nuclear wastes. Factors for use in preparing estimates of production of low-level waste, Cesium-137 and Strontium-90 isotopes, and spent fuel per unit of electricity produced in light-water reactors (both pressurized and boiling water reactors, PWRs and BWRs) are provided in Tables 4-1 and 4-2, below[43].

***Table 4-1: Range of Low-level Radioactive Waste Production per TWh of Electricity Generated*** [44, 45]

| | Cubic Meters | | Curies | |
|---|---|---|---|---|
| **Reactor Type** | High Est. | Low Est. | High Est. | Low Est. |
| **PWR** | 107 | 63 | 571 | 163 |
| **BWR** | 186 | 140 | 571 | 249 |

[43] These estimates were used in preparation of D. Von Hippel and P. Hayes (1997), Two Scenarios of Nuclear Power and Nuclear Waste Production in Northeast Asia, prepared for the Prepared for Yonsei University Department of Political Science. A version of this document can be found at http://www.nautilus.org/papers/energy/dvh_hayesNukeScenarios.pdf.

[44] R. Lipschutz (1980), Radioactive Waste: Politics, Technology, and Risk, Ballinger, Cambridge, MA; Report to the American Physical Society by the Study Group on Nuclear Fuel Cycles and Waste Management (1978), Reviews of Modern Physics, Volume 50, Number 1, Part II, American Institute of Physics, January, 1978; K. Lee, "Radioactive Waste", Chapter 14 in J. Dennis, Editor (1982?), The Nuclear Almanac: Confronting the Atom in War and Peace, Addison-Weseley Publishing Co., Reading, MA, USA.

[45] One curie (Ci) is a unit of radioactivity approximately equal to 37 billion atomic disintegrations per second.

***Table 4-2: Estimates for Use in Preparing Estimates of Production of Spent Fuel, Plutonium, Strontium-90 and Cesium-137*** [46]

| | |
|---|---|
| Mass fraction Pu in PWR/BWR spent fuel | 1% |
| Mass fraction Pu in HWR spent fuel | 0.4% |
| Grams U-235 fissioned per $MW_{th}$-day | 1.0 |
| Power plant efficiency ($TWh_e/TWh_{th}$) | 33.3% |
| Curies Strontium-90 per gm U235 fissioned | 3.0 |
| Curies Cesium-137 per gm U235 fissioned | 3.0 |
| Grams Pu fissioned per gm Pu in spent fuel | 1.0 |
| Curies Strontium-90 per gm Pu fissioned | 1.0 |
| Curies Cesium-137 per gm Pu fissioned | 3.0 |

| **For PWRs and BWRs:** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Years | $MW_{th}$-days/ Te Heavy Metal | Te Heavy Metal per MWth-day | Te Heavy Metal per TWhe | kg Pu in Spent fuel per TWhe | kg Pu Fissioned per TWhe | Ci Str-90 from Pu per TWhe | Ci Cs-137 from Pu per TWhe | Total Ci Str-90 per TWhe | Total Ci Cs-137 per TWhe |
| 1990 - 1999 | 40,000 | 2.50E-05 | 3.13 | 31.3 | 31.3 | 31,281 | 93,844 | 4.07E+05 | 4.69E+05 |
| 2000 - 2009 | 44,000 | 2.27E-05 | 2.84 | 28.4 | 28.4 | 28,438 | 85,313 | 4.04E+05 | 4.61E+05 |
| 2010 - 2020 | 48,000 | 2.08E-05 | 2.61 | 26.1 | 26.1 | 26,068 | 78,203 | 4.01E+05 | 4.54E+05 |
| **For HWRs (all)** | 7000 | 1.43E-04 | 17.88 | 71.5 | 71.5 | 71,500 | 214,500 | 4.47E+05 | 5.90E+05 |

Preparing estimates of the net coal mining wastes produced or avoided as a result of a grid interconnection is similarly straightforward in concept. Emission factors based on the type of mine (for example, surface or underground) and the type of coal seam mined (which affects the ratio of coal to rock), and the mining technique used are multiplied by the net change in coal for power production required, then summed over the plants whose output is affected by a grid interconnection.

On the other hand, preparing estimates of solid and hazardous wastes produced during power line construction, and during fuel cycle activities increased or decreased as a result of grid interconnections, is likely to be a much more site- and case-specific analysis, and much more qualitative, in many respects. Consideration must be given, for example, to the types of towers being installed, the size of the footings required, the types of soils to be encountered, and the age and composition of any existing equipment (for example, substation transformers or power plants) to be decommissioned.

Preparing estimates of the impacts of solid wastes on the environment is perhaps even more subjective, involving consideration of how and where solid wastes will be managed, stored, and disposed of, whether the wastes are liable to be rendered mobile in the environment (for example, by wind or water), and how they might come into contact with ecosystems, animals, or humans.

Sergei Podkovalnikov's paper for the Third Grid Workshop, "Environmental Impacts and Benefits of Regional Power Grid Interconnection for the Russian Far East: Generation and Fuel-Supply-Related Impacts", includes estimates of the impacts to the Russian Far East, in terms of

[46] In this Table $TWh_e$ and $TWh_{th}$ stand for Terawatt-hours of electricity and Terawatt-hours of thermal energy (that is, heat generated by the reactor), respectively. $MW_{th}$ is thermal megawatts, and Pu is the chemical symbol for Plutonium. HWR denotes values for heavy water-type reactors.

mortality per unit of electricity transferred over an interconnection, for scenarios of power export that depend on different types of generating resources, including nuclear generation.

In his paper "Environmental Impacts and Benefits of Regional Power Grid Interconnections for the Republic of Korea: Potential Impacts on Nuclear Power Generation and Nuclear Waste Production", prepared for the Third Grid Workshop, Dr. Jungmin KANG provides an estimate of the nuclear waste production in the ROK that might be avoided by a transmission interconnection, and of the economic benefit associated with the avoided waste disposal requirements[47]. Dr. Kang describes a case in which the availability of regional grid interconnections allow the ROK to avoid the construction of two future nuclear power stations, providing a significant decrease in the amount of nuclear spent fuel and wastes produced, as well as an (undiscounted) savings of nuclear waste storage and disposal of approximately 2 billion US dollars.

### 4.6. Generic Strategies for Maximizing Net Benefit of Transmission Line with Regard to Solid and Hazardous Waste Emissions

A number of general approaches can be considered in maximizing the net solid wastes-related benefits of operating a grid interconnection:

- Use the grid interconnection to substitute other types of generation for coal-fired generation as much as possible.
- Use appropriately sited and operated facilities to isolate any hazardous wastes, including PCBs from disposal old transmission facility equipment.
- Design power lines and hydroelectric dams associated with the interconnection so as to minimize the amount of earth to be moved.
- Avoid increasing nuclear waste generation.

Of course, some of these approaches may well be at odds with strategies for reducing air pollutant, water pollutant, and biodiversity impacts. A multi-objective (and collaborative) decision approach will therefore be needed, ultimately, in order to decide how to most effectively, from an environmental point of view, to build and operate a grid interconnection in Northeast Asia.

## 5. Impacts of Grid Interconnection on Land Use

### 5.1. Introduction

Grid interconnection projects can have both positive and negative impacts on land use. The construction and operation of transmission lines and associated facilities can result in permanent land conversion, land degradation, and the exclusion of traditional land uses in and around the transmission right-of-way. At the same time, changes in the fuel mix and power

[47] Available as http://www.nautilus.org/energy/grid/2003Workshop/Jungmin_KANG_final2.pdf.

generation patterns made possible by interconnection can lead to substantial, sometimes beneficial, changes in land use at other locations in the interconnected system. Land use impacts on non-transmission components of the fuel cycle, far from the transmission right-of-way itself, can be among the most significant in grid interconnection projects.

### ***5.2. Impacts of Construction and Operation of Transmission Line on Land Use***

The direct effects on land use caused by transmission lines and associated substations, conversion stations, and switchyards are of two basic kinds: damage to the land itself (including complete habitat conversion), and changes imposed upon pre-existing land uses. These effects can occur either during the construction phase or on an ongoing basis during normal operation.

As a type of land use, transmission rights-of-way and other transmission facilities have certain necessary features. Safe and reliable operation requires the elimination of fire danger, easy access for inspection and maintenance, and the prevention of vandalism, power theft, accidents, and unnecessary exposures to electric fields. These features are incompatible with many types of land use, including the presence of residential and commercial buildings and a variety of agricultural, commercial, and industrial activities.

Where these land uses already exist in an area to be traversed by a transmission right-of-way, they must be relocated. Where they do not already exist, transmission authorities and local governments must prohibit such uses. This includes ensuring that the right-of-way does not allow informal or illegal uses, for example in the case of farmers seeking to construct agricultural out-buildings on conveniently cleared and graded rights-of-way.

Examples of land uses that are not *necessarily* precluded by transmission rights-of-way include grazing, cultivation of low-statured crops, and infrastructure corridors for railroads, pipelines, highways, and foot traffic. Where pre-existing land uses are continued, they may nonetheless be affected by the presence of the transmission facilities and rights-of-way, for example in the case of power poles and guy wires forming a physical obstruction to the cultivation of agricultural land, or a hazard to low-flying aircraft. On the other hand, some land uses may be enhanced by the presence of right-of-ways and associated access roads, such as hunting and trapping, though this may constitute a problem for wildlife and biodiversity (see the next section of this paper).

Much of the construction-phase and ongoing damage associated with transmission lines results from land clearing for the transmission right of way itself. The total amount of land cleared will be:

Land cleared (ha) = 100 • [ ∑ {transmission line segment length (km) • right-of-way width per segment (km)} + {number of associated facilities • clearing for associated facilities ($km^2$)} - {transmission line segment length (km) • pre-existing right-of-way width per segment (km)}]

The total amount of clearing required depends on the transmission line routing and the right-of-way width, which may vary from one locale to the next (though a standard right-of-way width may be determined for the proposed NEA grid interconnection). A simple order of magnitude estimate, for transmission line lengths of a minimum of 1,000 to a maximum of 2,000 km, and right-of-way widths from a minimum of 50 m to a maximum of 200 m, yields a range of 5,000 to 40,000 ha cleared. From these values must be subtracted the amount of land already cleared for existing rights-of-way to be shared by the transmission line, such as the proposed

RFE-DPRK-ROK railroad right-of-way routing (Podkovalnikov, 2002[48]). In that case, land clearing for the transmission line will be just the incremental width required for the transmission line above and beyond the existing right-of-way width. The impact of transmission interconnections on forest lands is also noted in "The Potential Impact of the Inter-state Electric Ties in North East Asia on Environment", by the DPRK Delegation to the Third Grid Workshop, which estimates that perhaps 80 percent of the DPRK portion of the right-of-way for a RFE-DPRK-ROK interconnection would run through forested areas.

In addition to right-of-way clearing, the construction-phase can entail clearing for road-building and construction camps, and for industrial activities, such as gravel quarries and cement factories, to support the construction process.

The damages associated with the construction and operation of transmission facilities often includes the permanent conversion of habitats with high-statured vegetation such as forests and woodlands, and damage to soils and vegetation in other habitats such as grasslands and montane meadows. Where transmission lines traverse rivers and streams, or mountainous terrain, land surface disruptions can result in erosion and downstream siltation. Construction camps can entail multiple temporary land use impacts, including those associated with the need for water supplies, sanitation, waste disposal, building construction, electricity generation, and space heating. Permanent staffing of transmission facilities for operation and maintenance entails similar land use impacts on an ongoing basis, though generally at a smaller scale.

In addition to ecological damage and impacts on human habitation and economic activities, construction of transmission lines and rights-of-way can damage historical and archaeological sites, and sites of cultural and religious significance. Many people also object to transmission lines on aesthetic grounds, especially in scenic natural areas[49].

An important land-use concern is that the operation of transmission lines can significantly raise the likelihood of wild fire. Reduction of fire risk is a major reason that transmission rights-of-way must be kept clear of high-statured vegetation. Nonetheless, fires can be started when vegetation comes into contact with power lines, as may be the case when trees fall into lines due to storms or disease, or when lines are blown down by storms or sag due to ohmic heating during periods of high electrical loads. In many areas during certain seasons of the year, if these fires are not quickly contained, they may escape and cause great damage to forests, wildlife, human populations, and local economies. Another potential land-use impact of transmission line operation is electromagnetic interference with telecommunications lines and facilities, due to inductive linkages, corona, and ground loops, especially where power and telecomm rights-of-way are shared. Pipelines without cathodic protection that share transmission rights-of-way can also experience accelerated corrosion and premature failure.

### ***5.3. Impacts of Interconnection on Land Use for Power Generation Facilities***

Grid interconnection can lead to significant changes in the power generation regime in the interconnected system, as the timing and magnitude of peak demand, the availability of generation assets, and the priority order of economic dispatch change. The possible implications

[48] See footnote 1 for a complete reference to this paper.

[49] In "Environmental Characteristics of HVDC Overhead Transmission Lines", prepared for the Third Grid Workshop, Prof. L. A. Koshcheev, notes some of the aesthetic differences between HVDC and HVAC transmission lines.

for the construction and operation of individual generating facilities within the interconnected system include:

- interconnection may result in the need for certain new generating facilities to be built
- interconnection may eliminate the need for certain other new generating facilities to be built
- certain existing generating facilities may be dispatched more often, or at higher levels of output, as a result of interconnection
- certain other existing generating facilities may be dispatched less often, or at lower levels of output, as a result of interconnection

The net land use impact of generation will vary as individual facilities are added or avoided, or are dispatched more or less, as a result of interconnection. The impact will also depend on the features of each facility affected, such as its size, location, fuel type, and technology. Predicting the actual net land use impact must be based on power flow modeling and the specific features of the existing and proposed plants in the interconnected system, in comparison to a base case for the non-connected systems. Nonetheless, certain general observations may be made about land use impacts of different generation technologies.

In terms of entirely new facilities either added or avoided as a result of interconnection, hydroelectric facilities generally entail the most significant land use impacts per unit of capacity. The main hydroelectric land-use impact is the flooding of reservoir areas, followed by dam construction itself, and the disruption of downstream water flows. Dams may flood towns, wilderness areas, scenic and cultural sites, or agricultural areas, possibly entailing population relocations and/or changes in livelihood. As a rough rule of thumb, hydroelectric facilities under 100 MW capacity tend to require reservoir areas on the order of 200 ha/MW, while facilities in the 100-500 MW range require on the order of 100 ha/MW, and facilities larger than 1000 MW require on the order of 50 ha/MW. Thus, for example, the construction of 1 GW of new hydro to meet the capacity requirements of interconnection would be expected to submerge a minimum of 50,000 ha (which is more than the maximum rough estimate of land conversion for construction of the transmission right-of-way, 40,000 ha). In addition, reservoir construction can lead to additional land conversion and intensified land uses when populations and their associated livelihoods are relocated to new areas outside the reservoir.

Other offsite impacts of dam construction are associated with road building, construction camps, and materials supply. Both upstream and downstream changes in the flow regime of rivers can result in significant changes in fisheries and navigation, and their associated livelihoods. Changes in the operation of existing hydroelectric facilities are not likely to result in large additional land-use changes beyond the impacts of constructing the facility, except insofar as incremental changes in flow regime cause additional disturbances of ecosystems in the reservoir and downstream areas. (These are discussed in Section 6 of this paper, Impacts on Biodiversity and Wildlife.) Historically, hydro dam construction has sometimes led to substantial social and political conflict between predominantly urban groups who benefit from the electricity and groups in the reservoir area who suffer from displacement and economic disruption, or between relocated populations and existing populations in the areas to which the displaced populations are relocated.

Land use impacts of new thermal power plant construction include the permanent conversion of the power plant site itself, and possibly the creation of new transmission corridors and fuel supply lines if these do not already exist. The construction process can entail significant land use impacts of the sort already described in Section 5.2. Normal plant operations can affect land uses in the vicinity of the plant in several ways. For fossil fuel plants, air emissions may significantly affect the feasibility of residing, cultivating crops, or conducting commercial or industrial activities downwind of the plant. For all kinds of thermal power plants, cooling water requirements and thermal pollution may affect aquatic habitats and fisheries. For nuclear power plants, radiological contamination may persist long after the lifetime of the power plant is done unless the most stringent decommissioning and decontamination procedures are used. Radiological contamination limits future land uses at the former power plant site. Persistent chemical contamination from fuel storage facilities used for oil- and coal-fired power plants may also be a problem for future land uses after plant decommissioning.

The opposition of local citizens to power plant construction in heavily populated areas (some refer to this as the “NIMBY”, or "not in my backyard" response) is an important factor in power plant siting decisions in many countries. Although citizen opinions about the land use impacts of a generation facility may not necessarily be objective evaluations of those impacts, the avoidance of local opposition to new power plant construction by using grid interconnections to import power instead may well be seen by power system planners as an important land-use benefit of interconnection.

### 5.4. Impacts of Interconnection on Land Use for Other Parts of the Fuel Cycle

When the operation of existing generating facilities, or decisions to build or not to build new generating facilities, change as a result of power system interconnection, both upstream and downstream components of the fuel cycle associated with each generating facility will be affected accordingly, and land use impacts will be affected in turn.

Upstream fuel cycle land use impacts include those from changes in raw fuel extraction, fuel preparation, and fuel transportation. Downstream fuel cycle land use impacts include those from the transportation of waste and waste storage. The net land use impact associated with fuel cycle changes will be a function of the specific types of activities, technologies, and locations involved, and whether the changes are incremental increases and decreases, or entail the addition or avoidance of whole new upstream or downstream facilities.

Modeling of changes in land use impacts due to fuel cycle changes requires linking power flow models with resource models for non-interconnected and interconnected cases, and also requires a variety of assumptions about technology, demand growth, fuel prices, and dispatch protocols. At a general level, changes in coal-fired generation can result in increased or decreased land use impacts associated with coal mining, coal storage, coal transportation by train, truck, or slurry pipeline, coal washing and pulverization, limestone mining and transportation, and ash, slag, and FGD scrubber waste transportation and disposal. Changes in oil and gas generation can result in increased or decreased land use impacts associated with oil and gas extraction and pipeline construction and rights-of-way. Changes in nuclear generation can result in increased land use impacts associated with uranium mining and milling, fuel enrichment, fuel pellet, rod, and assembly manufacture, spent fuel disposal and reprocessing, and long-term nuclear waste storage. Fuel cycle impacts are often displaced, in the sense that the beneficiaries of the electricity supply can be quite different from those who bear the environmental consequences. For example, much of the ROK nuclear fuel cycle occurs outside the ROK, including in the U.S.

### ***5.5. Preparing Estimates of Land-Use Impacts***

Land use impacts due to power system interconnection result from the construction and operation of the interconnecting transmission lines and changes in the operating regimes and fuel cycle requirements of existing, and either added or avoided, generating facilities in the interconnected system.

Accurate modeling of the net land use impact of interconnection will require, for both the interconnected case and the non-interconnected (base) case:

- site-specific land-use requirements for the transmission line
- site-specific land-use requirements for every generating facility
- site-specific land-use requirements for every upstream and downstream fuel cycle facility

The generation and fuel cycle impact estimates will in turn require:

- estimated demand curves for future years
- power flow modeling linked to dispatch rules for the interconnected system
- ground rules for adding or avoiding future capacity
- resource requirements and emission factors for every generating facility as a function of capacity factor

A very rough estimate of land use impacts might focus solely on the land-clearing requirements for expected new facility construction, including the transmission line right-of-way and any generating facilities known to be required or avoided as a result of interconnection.

### ***5.6. Generic Strategies for Minimizing Net Land-Use Impacts of Grid Interconnection***

Generic strategies for minimizing net land-use impacts of grid interconnection include the following:

- Identify the most destructive land uses and the most sensitive areas within the interconnected system area.
- Make land use information widely available during the system planning and rule-making processes.
- Enlist the involvement of specialists in the ecological, social, and economic dimensions of land use in potentially affected areas.
- Solicit local citizen input in potentially affected areas.
- Plan construction alternatives for transmission lines that avoid or mitigate damage to the most sensitive existing land uses. These alternatives commonly include:
    - changing the routing of transmission lines
    - sharing existing rights-of-way
    - changing from overhead to underground lines, and vice-versa
    - changing tower and conductor heights

- changing tower types
- changing the appearance of towers
- changing construction practices.

- Devise rules governing capacity expansion and dispatch that favor lower-impact land uses in generation and other parts of the fuel cycle, in terms of the areas affected and the technologies/activities required.
- Institute demand-side management programs that reduce or eliminate the need for new capacity.

# 6. Potential Impacts of Interconnection on Biodiversity and Wildlife

## *6.1. Introduction*

The Convention on Biological Diversity defines biological diversity (or biodiversity) as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems"[50]. The impact of grid interconnection on biodiversity and wildlife results from the impact of the transmission line itself, plus the impacts on biodiversity and wildlife resulting from changes in the generation mix and fuel cycles of the interconnected system. Transmission line impacts are a function of where the line is built, the dimensions of the right-of-way, the extent to which pre-existing rights-of-way are used, tower and conductor design, and how the line is operated and maintained. If transmission line construction or operation stimulates the development of new settlements or commercial activities in rural or wilderness areas, this can also lead to impacts on biodiversity and wildlife.

Because a Northeast Asia grid interconnection may traverse sensitive habitats of global biodiversity significance, careful assessment of biodiversity and wildlife impacts is of special importance for project planning. Figure 6-1 identifies a number of Biodiversity "Hot Spots" within Northeast Asia.

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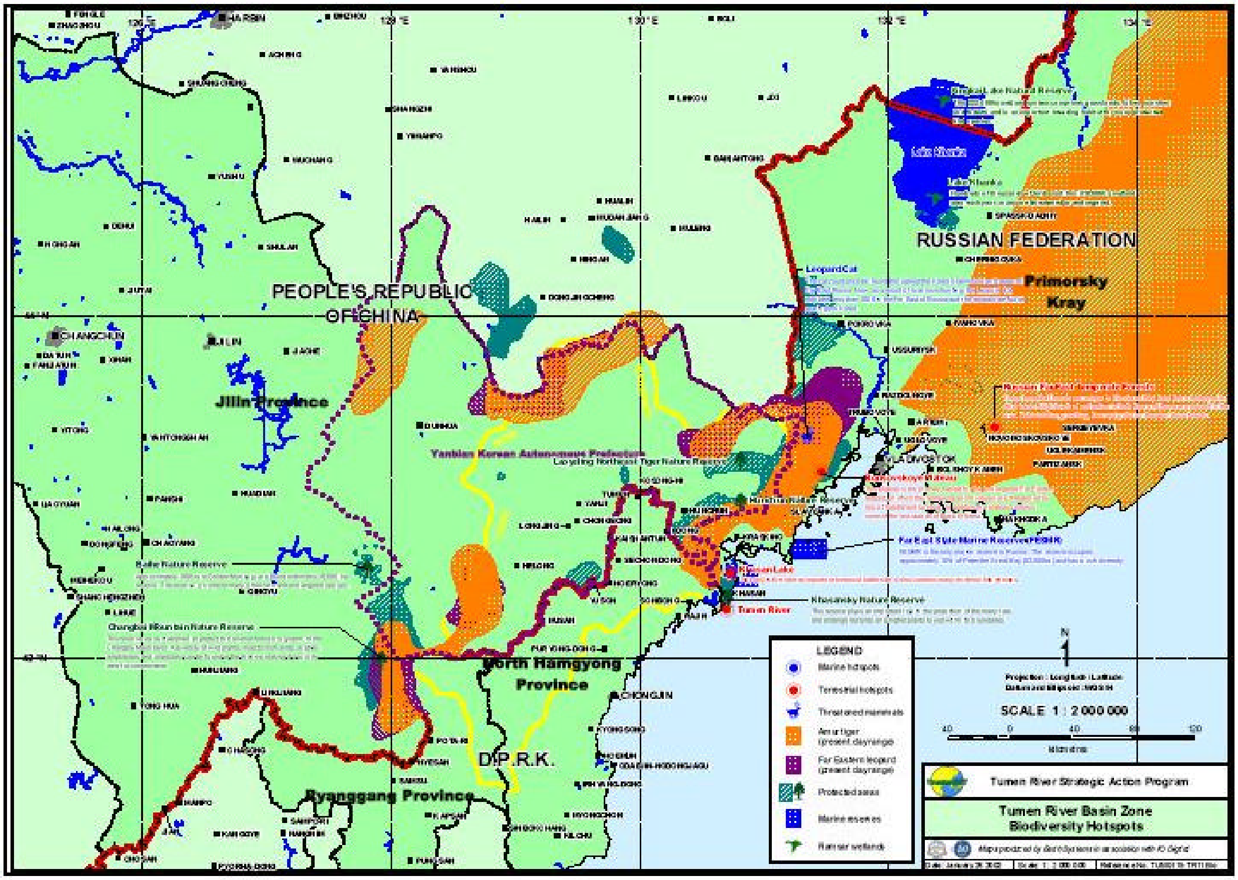
[50] Convention on Biological Diversity, Convention Text "Article 2: Use of Terms". Obtained from http://www.biodiv.org/convention/articles.asp?lg=0&a=cbd-02, visited 6/27/03.

*Figure 6-1: Biodiversity "Hot Spots"[51]*




## *6.2. Description of Territory Through Which Power Line May Run*

The routing of the Northeast Asia grid interconnection is still to be determined. For the purpose of considering the kinds of biodiversity and wildlife impacts that might result from interconnection, it is useful to consider the proposed RFE-DPRK-ROK routing (Podkovolnikov. 2002[52]). As described in Sect. 1.1 above, this routing follows where possible existing railroad right-of-ways. It connects in the north to the RFE grid at Vladivostok, traverses southwestward largely along the seacoast to the border of the Russian Federation and the DPRK. There the route continues southward along the east coast of the DPRK, turning just north of Wonsan to head approximately west across the Korean peninsula to the Pyongyang area. From the Pyongyang area, the route goes roughly south across the DMZ to the ROK border, and from there eastward into the Seoul area. A more detailed description of the Russian portion of a possible routing of such an interconnection, including details of land-types to be encountered, is provided in "Environmental Problems Associated with Power Transmission between Russia and

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[51] Map obtained from the TumenNET (Tumen River Strategic Action Program, UNOPS/GEF/UNDP) web site http://www.iodigital.com.au/tumennet/download.asp as file TR11Bio.PDF.

[52] See footnote 1 for complete reference to this document.

the Korean Peoples' Democratic Republic", by Dr. Nikolai D. Gamolya[53]. This paper also provides a listing of the potential environmental impacts of a power line interconnection, with an emphasis on land use and biodiversity impacts. Another paper prepared for the Third Grid Workshop, "The Environment of, and Environmental Regulations in, the Russian Far East" by Prof. Alexander S. Sheingauz, provides a detailed description of the topography, ecology, and environmental problems of the Russian Far East[54]. This description is further elaborated by a paper by Dr. Vladimir Karakin, "Main Ecological and Resource Issues of the Russian Part of the Tumen River Area", which focuses on biodiversity, and threats to biodiversity, in the Southwestern Primorye area of the Russian Far East[55]. A paper by Dr. Yuri Shibaev and Dr. N.M. Litvinenko entitled "Birds and the Proposed 500 kV Power Transmission Line: Potential Impacts in the Southern Part of Khasanskii District on the Primorskii Krai", provides a further focus on avian biodiversity in the border region where Russia, China, and the DPRK come together. The latter paper also provides discussions of local and national legislation to protect birds in the area, discusses threats to birds from power line development, suggests a monitoring program to help identify biodiversity trends, and identifies measures for prevention of and compensation for loss of birds[56]. A presentation at the Third Grid Workshop by Mr. Hall Healy provides a regional context for issues related to migratory birds that pass through the border region[57].

Along the proposed RFE-DPRK-ROK routing described above, both level and mountainous terrain is traversed, encompassing a variety of habitats or ecosystem types. These habitats, and the plant and animal communities that compose them, form the basis of regional biodiversity. Species cannot survive without functioning habitats, because habitats provide the food and the environments for reproduction and raising of young that the species require. Most endangered species are endangered primarily because the habitats to which they are evolutionarily adapted have been destroyed or heavily degraded.

Major habitat types that the NEA interconnection may traverse include forests, wetlands, riparian zones, and rivers and streams. Some of their main values and vulnerabilities include:

- Forests. Forests in the NEA region provide habitats for tigers, leopards, bears, lynx, badgers, and numerous other charismatic mammal species. They are also essential to humans for supplies of food, fuel, and fiber. Forests are vulnerable to many kinds of human impacts, including cutting, fire, and the introduction of invasive species, pests, and diseases. Forest-dwelling animals are often particularly vulnerable to hunting, trapping, and noise disturbance.
- Wetlands. Wetlands are the most productive habitats on earth (in terms of biological net primary productivity) and form the foundation of many aquatic and terrestrial food chains. They provide essential habitats for waterfowl and migratory birds, including rare and endangered species such as cranes. Wetlands are also essential to human well-being.

[53] Please see http://www.nautilus.org/energy/grid/2003Workshop/papers.html.

[54] Please see http://www.nautilus.org/energy/grid/2003Workshop/ecol_paper_sheingauz_final1.pdf.

[55] Please see http://www.nautilus.org/energy/grid/2003Workshop/papers.html.

[56] Please see http://www.nautilus.org/energy/grid/2003Workshop/papers.html

[57] This presentation will be available on http://www.nautilus.org/energy/grid/2003Workshop/papers.html

Coastal wetlands are nurseries for great pelagic fisheries. Wetlands filter silt and pollutants in runoff from land to rivers and bays, providing natural wastewater treatment, and up to a point can prevent upland erosion from degrading waterways. Wetlands are vulnerable to changes in hydrologic regimes, excessive siltation rates, and direct habitat destruction because of the limited area of remaining wetlands. Wetland birds are especially sensitive to noise and disturbance.

- Riparian zones. Riparian zones (land adjacent to rivers and streams) are extremely productive for their relatively small extent, containing high diversity and density of birds and small mammals. Riparian zones protect streams by limiting silt loads and regulating microclimates (for instance, by providing shade from the sun). Riparian zones are vulnerable to the removal of native species, and to upslope disturbances that cause excessive erosion or land slides. Construction of linear facilities (such as railroads and power lines) parallel to rivers and streams can constitute a serious threat to riparian habitats.
- Rivers and streams. Rivers and streams are habitats for fish and other aquatic species. Riverine fish and insects provide food for birds and mammals that are not themselves aquatic, and also provide food and water to humans. They are also important to humans for scenery and recreation. Riverine habitats are vulnerable to changes in riparian vegetation, to pollution, and to changes in flow regimes, which can alter stream channels and water temperature, and can undercut banks.

### ***6.3. Potential Impacts of Transmission Line on Biodiversity and Wildlife***

The potential impacts of a transmission line on biodiversity and wildlife result from the interaction of species and their habitats with the physical features of the facility itself – rights-of-way, conductors, towers, and substations – and the activities and hazards associated with building, operating, and maintaining the transmission line and substations. These activities include land clearing, construction work, herbicide spraying, fire hazards, and hunting, trapping, and poisoning of animals. In addition to direct impacts on individuals and species, transmission facilities and associated hazards can also affect them indirectly by altering natural relationships and competitive balances.

The transmission right-of-way can entail direct conversion of significant amounts of habitat; as estimated in Section 5.2, this could range from 5,000 to 40,000 hectares for the NEA grid connection project, minus the area of existing rights-of-way used. Regardless of the total magnitude, any conversion of rare habitats may significantly affect the likelihood of survival of species endemic to those habitats.

Short of outright conversion, rights-of-way can also fragment habitats into smaller pieces, by creating a strip of cleared land that forms a barrier to the movement of some species. This fragmentation decreases the likelihood that everything an organism requires for survival will be available to it. Forest-dwelling species often avoid cleared areas because open sightlines make them more vulnerable to predators. Fragmentation of wetlands can change hydrologic regimes, creating habitats that are too wet or too dry at specific times of the year for the species living there. The meeting of right-of-way clearings with uncleared habitat can also result in edge effects, in which invasive species are introduced, changing microclimates and increasing the vulnerability of plant communities to pests and diseases.

Access roads present habitat fragmentation hazards similar to those of rights-of-way. In addition, new access roads may result in human impacts on biodiversity and wildlife distant from the transmission lines themselves, by opening areas previously difficult of access to activities such as construction, extraction, and hunting.

Transmission line conductors and towers can present hazards to wildlife. Birds can fly into power lines, especially at night. Predatory birds may perch on lines and towers and obtain an unnatural advantage over prey species, upsetting natural balances. Birds and small mammals are also at risk of electrocution in the vicinity of energized conductors.

During construction, land clearing can directly destroy wildlife, nests, and water and food sources. Where fire is used for clearing, there is the potential for the fire to escape to surrounding areas and cause consequent habitat destruction. Disturbance of soil and surface vegetation can lead to erosion and siltation, affecting wetland and aquatic habitats; the raising of large amounts of road dust can also lead to siltation. Wetland soils are especially vulnerable to compaction from heavy construction equipment, which can also damage water channels and permanently change hydrologic regimes. Noise from construction activities can drive both predators and their prey away from home ranges, and can seriously disrupt mating activities.

Operation and maintenance of transmission facilities and rights-of-way presents several threats to biodiversity and wildlife. An important threat is the increased risk of fire from power line interactions with trees; wildfires can escape and destroy large amounts of wildlife habitat. At the same time, the spraying of herbicides to reduce fire danger in rights-of-way – especially when aerial spraying is involved – can result in indiscriminate plant mortality and habitat damage in areas surrounding the right-of-way. Herbicides can also wash into lakes and streams, resulting in acute or chronic impacts on aquatic species.

Birds and small mammals can sometimes cause electrical faults in substation equipment, either when they bridge energized and grounded components with their bodies, or when they introduce materials – such as wet grasses for nests, or excrement – that create a fault. Such faults can have serious consequences, including fires and transformer explosions, resulting in outages and endangering surrounding areas with fire and possible PCB/Dioxin contamination if these materials are used in transformers. To prevent such occurrences, in many parts of the world operations and maintenance personnel have sought to protect substation components by shooting, trapping, or poisoning birds and small mammals. Only relatively recently in the U.S. have such practices been vigorously ended, and alternative protection methods employed (see below).

Finally, the presence of operation and maintenance personnel, and the access of other people unrelated to the transmission facility to the right-of way and its surrounding area via access roads, can lead to increases in hunting and poaching in sensitive habitat areas.

### ***6.4. Non-Transmission Effects on Biodiversity and Wildlife, Including Avoided Impacts in Generation and Fuel Cycle Effects***

Changes in generation patterns and new-capacity decisions due to interconnection also have potential impacts on biodiversity and wildlife, including possible beneficial effects. To the extent that the construction of new generation facilities is avoided altogether, entire habitats may be spared from conversion or degradation. For example, the avoidance of new hydroelectric dam and reservoir construction spares both the terrestrial habitat to be flooded and the species in that habitat, as well as aquatic habitats and species up and down stream from the reservoir area.

Changes in generation patterns are likely to have complex implications for biodiversity and wildlife. Increased use of hydroelectric generation may affect the timing of releases and the availability of water for maintaining biologically-important flows, leading to phenomena such as increases in water temperature, scouring of banks, and changes in turbidity, all of which can affect aquatic species, and even terrestrial species that depend on streams for food and water.

Increased use of fossil fuel-fired power plants can have many negative impacts on biodiversity and wildlife. Air emissions of sulfates and nitrates can result in acid rain, often in distant areas, reducing forest health. Nitrate emissions also lead to excessive nitrate fertilization, which strongly favors some plant species to the detriment of others, with consequences for pollinators and predators. Increased emissions of trace chemicals found in fossil fuels, such as lead, mercury, uranium, and thorium increases the presence of these toxic substances in the environment, and the potential for their bioaccumulation in food chains. Increased fuel requirements for fossil fuel-fired generation can lead to habitat conversions or degradation due to increased surface mining, fuel processing and transportation, and to acid mine drainage that can kill aquatic and riparian species.

Increased use of all thermal power plants, including nuclear plants, can lead to increased use of cooling water and thermal pollution of water bodies, with impacts on aquatic species. Increased carbon emissions also constitute an incremental contribution to the global biodiversity impacts threatened by climate change.

There are likely to be both negative and positive impacts of any given change in generation pattern due to interconnection, for instance if hydro generation tends to replace fossil fuel generation, or nuclear generation replaces either hydro or nuclear. To the extent that the net result is to reduce the most damaging impacts on the most sensitive habitats and species, the overall effect of interconnection on biodiversity and wildlife could be considered positive.

### ***6.5. Strategies for Reducing Impacts on Biodiversity and Wildlife***

Many transmission utilities around the world have adopted guidelines for the protection of biodiversity and wildlife, in order to ensure that construction and operation of transmission lines conform to national and local environmental laws and the requirements of international lenders such as the World Bank. Common practices for protecting biodiversity include:

- Conducting a thorough Environmental Impact Assessment that considers potential impacts on all sensitive habitats and species and mitigation alternatives, including alternative routings through less sensitive habitats
- Cooperating closely with local environmental protection agencies in the planning stages, and also actively soliciting participation in the planning process by outside experts such as ecologists and wildlife biologists in academic institutions and environmental NGOs
- Implementing Integrated Vegetation Management (IVM) strategies that simultaneously reduce fire danger and mitigate right-of-way impacts. Some “best practices” in IVM include encouragement of tree growth up 3-4 m to provide habitat and reduce fragmentation effects, and integrated pest management techniques that minimize herbicide and pesticide use.
- Adapting transmission line and tower design to protect sensitive species, for example by lowering transmission line heights in flyways, and making conductors more visible to birds (for example, with marker balls and lighting).

- Adapting construction techniques to protect sensitive habitats, for example by only doing construction work in wetlands in seasons when the ground is frozen, in order to avoid soil compaction and damage to waterways.
- Minimizing the accidental introduction of invasive species during construction, for example by cleaning construction equipment thoroughly of soil and plant matter before moving into a new construction area.
- Raising tower and conductor heights at river crossings and across sensitive habitats to reduce tower impacts
- Working with fish and game officials to strictly enforce rules regarding fishing, hunting, and trapping in and around transmission rights-of-way
- Employing techniques such as compressed air horns to discourage birds from nesting in substations, as an alternative to shooting or poisoning

Specific suggestions for protecting biodiversity in the Southwest Primorye area of the Russian Far East are included in the paper prepared by Dr. Vladimir Karakin for the Third Grid Workshop, and include improving the system of protected territories in the area, tiger and leopard conservation, conservation and restoration of the most valuable ecosystems, conservation of marine biodiversity and coastal landscapes, conservation of bird fauna, and anti-poaching activities, along with economic development in the region in a way that goes hand in hand with protection of biodiversity[58].

In addition to transmission line impacts, impacts on biodiversity and wildlife in generation and other parts of the fuel cycle can be minimized by incorporating these concerns in construction decisions and in dispatch protocols for the interconnected system. For example, in comparing different generation alternatives for new capacity to be added to the system, such as the question of whether to build thermal or hydropower plants, comparisons of the biodiversity and wildlife impacts should be considered along with economic and engineering criteria. As in the case of the consideration of transmission line biodiversity impacts, this entails environmental impact assessment and the solicitation of expert opinion from an early point in the design and decision-making processes.

## 7. Potential Impacts of Grid Interconnections on Human Health

### ***7.1. Introduction***

The net impact of grid interconnection on human health is a function of the direct health impacts of transmission lines and the indirect impacts of changes in generation. Transmission lines and substations can represent a hazard to the health of workers and the general public, from electrical shock, explosions, fires, the accidental dispersion of dioxin-containing PCBs, and possibly from chronic exposure to low-frequency electromagnetic fields (EMFs). At the same

[58] Please see http://www.nautilus.org/energy/grid/2003Workshop/papers.html.

time, interconnection can lead to generation and fuel cycle changes that can improve or worsen human health effects.

### ***7.2. Direct Impacts of Transmission Line Construction and Operation***

Electromagnetic fields produced by AC electrical equipment and power lines are referred to as EMFs. As these fields occur at frequencies of 50 Hertz (Hz) or 60 Hz and their harmonic frequencies, these fields are also sometimes referred as "Extremely Low Frequency" EMFs, or "power-line frequency" EMFs.

Health concerns have centered around three kinds of effects that some researchers have associated with chronic exposures to EMFs: (1) childhood leukemia (2) adult leukemia (acute lymphocytic leukemia) and other cancers (3) effects on pregnant women, including spontaneous miscarriage. To date, scientific evidence regarding the magnitude, threshold levels, and even the existence of these effects remains uncertain and conflicting.[59] The strongest evidence for the existence of these effects has come from epidemiological studies linking these effects to chronic exposures to high levels of EMF. However, controlled laboratory tests and other epidemiological studies have shown no effects, leaving the scientific community without a strong consensus on the EMF question. Another difficulty is the lack of a compelling model of the physiological mechanisms by which EMFs might produce health effects. What is known is that if such effects exist, they are probably the result of the magnetic component of the EMF, which induces microscopic currents within the body, with maximum current densities for typical chronic exposures being on the order of 1-10 $mA/cm^2$.[60]

Studies indicate that the largest source of EMF exposures for many people are in the household and office, coming from house wiring, computer monitors, and poorly shielded appliances such as microwave ovens. For others, the main exposure comes from overhead AC distribution lines and pole-mounted transformers near their houses. Average exposures in the U.S. are in the range of 1 milligauss, with much less than one percent of the population having exposures of 10 milligauss or more. Relatively few people live close enough to overhead high voltage AC transmission lines to receive a large exposure, but in cases where residences abut transmission rights-of-way, higher exposures are possible. For 500 kV lines, peak field strengths at the edge of transmission rights-of-way can reach 100 milligauss, and average in the range of 25-50 milligauss.

EMFs aside, the main human health risks associated with transmission lines and substations are occupational. Accidental electrocution and the explosion of overloaded transformers and switchgear are ongoing hazards in utility operation and maintenance. Fires started when trees and power lines interact can threaten workers and residents in the vicinity. Power lines knocked down by storms also represent electrocution hazards for the public.

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[59] Christopher Portier and Mary S. Wolfe, eds., *Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields: NIEHS Working Group Report,* National Institute of Environmental Health Sciences of the National Institutes of Health, 1998.

[60] John Harte et al, *Toxics A to Z: A Guide to Everyday Toxic Hazards*, Berkeley: U.C. Press, 1992.

### ***7.3. Indirect Impacts of Interconnection on Human Health***

Electricity generation and its associated fuel cycles produce a vast array of human health impacts, with air pollution, water pollution, and accident hazards during construction and normal operation of power plants, mines, and fuel transport systems being among the most significant hazards. As in the case of other environmental dimensions of grid interconnection, the net human health impact of interconnection will vary as individual generating facilities are added or avoided, or dispatched more or less. The impact will depend on the capacity, fuel type, and technology of each facility, and on its proximity to human populations and their food and water sources.

For example, as discussed previously in Section 2, coal-fired power plants emit sulfates, nitrogen oxides, and particulates (at levels that reflect the fuel quality and pollution control technology used in the plant) all of which are associated with significant health impacts on human respiratory and cardiovascular systems. They also emit metals such as mercury and lead, and radioisotopes such as uranium and thorium, which constitute neurotoxicity and cancer risks, respectively. To the extent that interconnection replaces relatively dirty coal generation with cleaner sources, all other things being equal, reduction of air pollution impacts on human health can result.

### ***7.4. Strategies for Reducing Impacts on Human Health***

Despite the lack of conclusive evidence for EMF health effects, health and regulatory authorities in many countries have taken a prudential, “no-regrets” approach toward limiting public EMF exposures. In California, for example, for new transmission projects utilities are required to spend up to 4% of project cost on reducing EMF, with the cost-effectiveness requirement that this expenditure reduce average field strengths at the right-of-way edge by at least 15%.

For AC transmission lines, EMF exposures can be reduced by reducing ground-level field strengths. Techniques include burying conductors underground, shielding conductors, raising overhead conductors to greater heights, reducing the distance between the three conductors in 3-phase AC systems (which causes the fields to cancel each other more effectively), and reducing current (since magnetic fields are a function of current). EMF exposures can also be reduced by keeping the public at greater distances from conductors, typically by widening the right-of-way and restricting public access to the right-of-way. Underground burial is another option, but is often quite expensive, costing from 2-10 the cost of comparable overhead transmission lines. Underground burial is usually undertaken only in densely populated urban areas, primarily for safety and aesthetic reasons apart from EMF exposures. Shielding is another method of reducing EMF exposures, but is also expensive and is usually restricted to substation equipment. Increasing conductor heights is the approach most commonly employed in the U.S., as this adds only incrementally to the cost of new transmission lines and their operation and maintenance.

The use of DC transmission lines eliminates EMF concerns, as there is no time-varying current and hence no magnetic field. Static electric fields, which are a function of voltage, have not been shown to have any associations with health effects at the field strengths associated with power lines or other ordinary exposures. A paper prepare for the Third Grid Workshop by Prof.

Lev A. Koshcheev, "Environmental Characteristics of HVDC Overhead Transmission Lines", describes the differences between HVAC and HVDC transmission lines with regard to EMFs[61].

Since economic tradeoffs inevitably occur in transmission line design, planners should be careful that investment in preventing possible low-level health effects of EMFs are in reasonable proportion to other investments in health, safety, and environmental protection. For reducing health effects in generation and other parts of the fuel cycle, strategies identified in previous sections for maximizing air, water, and solid waste benefits may be applied. The wide variety of possible costs and benefits related to the impact of interconnection on generation patterns and up and down stream fuel cycles, and the widely varying locations and affected populations, mean that a full consideration of what the impacts are and where best to concentrate resources to protect human health is an exercise in informed, but ultimately subjective, judgment. Many trade-offs will be involved that can't be reduced to quantitative terms. One way of ensuring that as many qualitative dimensions of human health impacts as possible are at least taken into consideration in planning decisions is to involve representatives of potentially affected communities.

# 8. Institutional Issues Associated with the Environmental Performance and Regulation of Grid Interconnections

## ***8.1. Introduction***

A grid interconnection in Northeast Asia will likely involve at least three and possibly four different countries, each with its own regulations and practices for construction and operation of major transmission lines and of power generation facilities. In addition, to the extent that international financing (or partial financing) of a grid interconnection is available and desired, international financial institutions may impose their own regulations for environmental assessment on a grid interconnection project. As a consequence, coordination between countries will be necessary to make sure that all relevant environmental performance standards of a grid interconnection are agreed upon and met. The remainder of this section of this paper briefly reviews the existing national regulations and practices that might affect how a grid interconnection is constructed and operated. Also offered below are some initial ideas on the types of coordination between countries that might be needed—and strategies for implementing coordination—to ensure that the environmental performance of a grid interconnection meets all standards and improves upon the no-interconnection situation. Examples of existing national and international programs, involving the Russian Far East, that include some of the kinds of cooperative strategies described below can be found in section 5 of "The Environment of, and Environmental Regulations in, the Russian Far East" prepared by Prof. Alexander S. Sheingauz for the Third Grid Workshop[62].

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[61] Please see http://www.nautilus.org/energy/grid/2003Workshop/Koshcheev_paper_final1.pdf.

[62] See http://www.nautilus.org/energy/grid/2003Workshop/ecol_paper_sheingauz_final1.pdf, as noted above.

## *8.2. Existing Environmental Regulations Related to Interconnection, and Institutions Responsible for Environmental Regulations in the Power Sector*

Three papers prepared for the Third Grid Workshop provide overviews of the regulatory institutions and situation in the Republic of Korea, China, and Russia. These papers are:

- "Codes, Practices, and Regulations for Major Power Line Construction and Operation in the Republic of Korea, with a Focus on Environmental Protection", by Suhmoon Cheol and Hwang Jong-Young;
- "Environmental, Technical and Safety Laws, Regulations and Standards Related to Power Line Construction in China", by Zhao Yong and Wang Fei; and
- "Environmental, Technical, and Safety Codes, Laws and Practices Related to Power Line Construction in Russia", by Andrew S. Gerasimov[63].

The paper on ROK regulations authored by Mr. Suhmoon Cheol and Dr. Hwang Jong-Young summarizes the many ROK codes and Acts on different topics—ranging from urban planning to natural parks to atomic energy—with which transmission line projects need to comply. A description is also provided of the "Act on Special Cases Concerning Electric Source Development", which is designed to streamline the regulation and approval process for critical electricity facilities. A description of the requirements for environmental impact assessment under this Act is also provided. A listing of technical and related standards for transmission line construction is also provided.

In their paper on the laws and regulations relating to power line development in China, Prof. Zhao Yong and Dr. Wang Fei provide an overview of the environmental codes that must be complied with by transmission line project in China, and identify the process by which environmental protection is assured in such projects, from the pre-feasibility study stages to the operational stages. Procedures for environmental impact assessment for transmission line projects in China are also described, as technical standards for power line construction and safety codes for power grids. The paper includes a case study of the regional environmental impacts of interconnection in Southern China.

Dr. Andrew Gerasimov's paper on the regulations related to power line construction in Russia includes a review of codes and standards related to power line insulation and grounding practices, conductor height under various situations, and standards for the environmental performance of transmission lines, including electromagnetic noise, field strengths, and induced currents.

These papers, in combination, provide an excellent reference to the array of laws and administrative procedures that would need to be satisfied by a transmission line interconnection project involving any or all of the three countries. A fourth paper, focusing on the Russian Far East (the Environment of, and Environmental Regulations in, the Russian Far East", by Prof. Alexander S. Sheingauz, includes substantial detail on environmental regulations—particularly

[63] Available as http://www.nautilus.org/energy/grid/2003Workshop/Paper_suhmoon_final.pdf, http://www.nautilus.org/energy/grid/2003Workshop/M_Zhao_PPR.pdf, and http://www.nautilus.org/energy/grid/2003Workshop/Gerasimov_paper_final1.pdf, respectively.

as they affect impacts on land use and biodiversity—and provides a listing of the steps that an electricity network project must go through to receive administrative approval[64].

### *8.3. Types of Environmental Coordination Needed*

Several types of coordination between nations, and between organizations within nations, will be needed to ensure environmental protection with power line design, construction and operation. The types of coordination needed will likely include:

- Coordination on assessment of the environmental impacts of a grid interconnection, which itself will necessarily require technical assessment of interconnection options, and modeling to determine the impact of an interconnection on the operation of elements of grid systems of the interconnected countries.
- Coordination on basic research on the flora and fauna that inhabit proposed power line routings, and particularly in those areas where populations and ecosystems span borders.
- Coordination on the monitoring of environmental impacts of power line construction activities and power line operations, as well as coordination in setting policies for the interconnection based on the results of individual or collaborative research. That is, if research by a country or a consortium of countries identifies an environmental issue associated with the grid interconnection, there must be a mechanism for the research results to be taken into account in planning future operation of the interconnection.
- Coordination in the design and construction of the power lines for the grid interconnection to assure that the lines meet technical and environmental specifications of the countries involved. Coordination will also be needed to assure that power line construction and maintenance activities comply with both practices and regulations in the interconnected countries, as well as with practices and regulations agreed upon for the interconnection as a whole.
- Coordination in the operation of the grid interconnection to ensure that the optimal environmental (as well as technical and economic) benefits of a grid interconnection are realized, to the extent possible, at each scale (local, regional, and global) of environmental impacts. This coordination will require a system of data collection and sharing on the electricity grids of each of the interconnected nations so that assessments of the environmental impact of the transmission line can be carried out on a regular basis.

It is very possible that the use of funds from international agencies and/or multilateral donors will impose on an interconnection project additional requirements for environmental assessment and monitoring, as well as on the environmental aspects of power line construction and operation. Examples of (and references to) some of these requirements are described in a paper prepared for the Third Grid Workshop by Dr. James H. Williams, entitled “International Best Practices for Assessing and Reducing the Environmental Impacts of High-Voltage Transmission Lines”[65]. Dr. Williams’ paper begins with a brief overview of the types of transmission line impacts described above, discusses widely-accepted approaches and methods

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[64] Please see http://www.nautilus.org/energy/grid/2003Workshop/ecol_paper_sheingauz_final1.pdf.

[65] Please see http://www.nautilus.org/energy/grid/2003Workshop/Env_Best_Practices_Williams_final.pdf.

for assessing and reducing transmission line impacts, reviews the environmental requirements relevant to transmission line projects set by the World Bank and the Asian Development Bank for Bank-funded initiatives, describes, as a case study, the environmental assessment and mitigation dimensions of a recent transmission project in Asia that has received support from international financial institutions, and concludes with observations on the relevance of past experience to the Northeast Asia grid interconnection project.

### ***8.4. Potential Strategies for Coordination***

Accomplishing the types of coordination described above will require the formation of organizations with representatives from each country. Several ideas for strategies to coordinate the efforts in environmental assessment and monitoring, and in assuring good environmental performance by the grid interconnection, are provided below. Note that these ideas are extremely preliminary, and are expected to be elaborated upon, augmented with new ideas, or discarded if appropriate, based on the outcome of discussions in the Third Grid Workshop.

- Establish a **network of researchers** working on environmental issues related to grid interconnections. Such a network would include scientists and engineers from each of the countries of the region, and could include representatives from universities, non-governmental organizations, and governmental institutes. The network could have regular meetings and/or could exchange information through an internet site set up for the purpose. The network would serve as a means of sharing information and ideas regarding the assessment of the potential environmental impacts of a grid interconnection.
- Establish (or augment) a **collaborative modeling group** working on the interconnection issue. Several of the countries of the region have already begun to develop such collaborative modeling efforts to investigate the technical (for example, grid stability) and economic aspects of grid interconnections. Building onto these efforts to add group members with expertise and interest in modeling the environmental aspects of grid interconnections would help to make sure that such investigations are done in a thorough and timely manner. This group could be involved in and/or advise the process of environmental assessment that will likely accompany any pre-feasibility or feasibility studies of grid interconnection.
- Once an interconnection project has been approved, it will likely be necessary to establish a **commission** with representatives, for example, from the grid operators and environmental ministries in each of the countries involved, as well as representatives from multilateral lenders or other organizations (if applicable). The mandate of the commission would be to **monitor the environmental performance of the grid interconnection**, including assuring that an agreed level of compliance with the environmental laws in each nation are maintained in the construction and operation of the interconnection, and also to collect information enabling the net environmental performance of the interconnection to be monitored over time. To the extent that targets/mandates for environmental performance are not explicitly associated with the approval of the project by governments and lenders, this commission would be responsible for establishing such targets and mandates at the outset of the project.
- When the operation of the interconnection begins, an entity will need to be created to **oversee the operation of the interconnection**. This entity—quite possibly a team of technical experts overseen by a board with members from each country—would be charged with making daily decisions about the operation of the line (in consultation with grid operators in

each country) and also with making long-term policy decisions about the operation and other aspects of the interconnection. Among these responsibilities would be the operation of the interconnection so that it meets the environmental goals set at the beginning of the project, and providing data on the day-to-day operation of the transmission interconnection so that others can review the performance of the link.

As noted above, these recommendations are very preliminary, and not particularly specific. It is hoped that discussions during the Third Grid workshop can help to develop or add to these ideas, and help to identify how these ideas (and others) might fit in with collaborations and work by others already underway in the region.

## 9. "Next Steps" in the Exploration of the Environmental Impacts of Grid Interconnections

### *9.1. Introduction*

The goal of this section is to provide a summary of potential "next steps" in the exploration of the environmental impacts of Grid interconnections, based in part on the suggestions for coordination provided above. This section also indicates, preliminarily, how these "next steps" would fit into other needed planning for an interconnection, and offers opportunities and suggestions for follow-up in order to begin the implementation of the next steps. This section has been built in part upon the results of discussions that occurred during the Third Grid Workshop.

### *9.2. Potential Next Steps*

A number of suggestions for potential "next steps" in the evaluation of the environmental impacts (net costs and benefits) of grid interconnection possibilities are provided below. In many cases, these next steps could be undertaken in the context of one (or more) of the coordination strategies described in the previous section of this paper.

1. Building of **database** of information for more detailed modeling of regional power system operation with and without an interconnection. This was one of the recommendations from the Second Grid Workshop. Building a database of information for detailed collaborative modeling of "business as usual" and interconnected regional power system scenarios is a prerequisite to determining many of the net environmental impacts of power system interconnection. The database would, ideally, contain information on the technical, economic, and environmental aspects of power system elements in each country, and would be shared within a collaborating regional modeling group. The data template presented in Annex B to this paper shows some of the types of information that could be included in such a database. Of course, the requirements for data, and the form of the data required, will to some extent be dictated by the choice of the modeling system to be used.
2. **Collecting more general information** for dissemination to researchers and policymakers, as well as for training. Collections of papers such as those prepared for this workshop, augmented by other materials, including codes and standards from the countries of the region with which grid interconnection projects may need to comply, as well as environmental

assessment rules from international financial institutions, will provide a critical resource to help expedite the evaluation of the environmental impacts of grid interconnections. In addition, such a compilation, augmented, for example, by study tours and other targeted training activities, can play an important role in allowing all potential interconnection partners to fully participate in the evaluation of integration options[66].

3. Modeling of **different dispatch impacts of interconnection**, with calculation of net emissions and other environmental impacts of interconnection. With a database in place, a collaborative group could proceed to use dispatch and economic models to assess the relative impacts of grid interconnection on generation in different power plants under different scenarios. This modeling could be done collaboratively by a multi-national group of researchers using a single modeling system, or could be done by several different groups of researchers working with their own modeling systems. In the latter case, modeling groups would meet to discuss and reconcile their results, and in either case the modeling effort would be expected to be part of pre-feasibility and feasibility analyses of grid interconnections.

4. Further analysis of the **ecological sensitivity of areas to be traversed by power lines**. As proposals for specific interconnection routings become more concrete, more detailed assessment of the ecological sensitivity of those areas through which the power lines will pass should be carried out. Areas near borders, in particular, will likely be best evaluated by teams of researchers from both (or all) of the nations sharing the border region.

5. Further analysis of methods of **amelioration of power line impacts**, and enhancement of benefits. Additional research will be needed, both within the literature and experience of the countries of Northeast Asia and within the international literature, into methods by which the impacts of constructing and operating power lines can be minimized, as well as methods by which power line benefits can be maximized. Research into methods of amelioration of impacts will include finding information on applicable technical solutions, their cost, and their effectiveness in solving environmental problems. Research into ways that the benefits of grid interconnection can be enhanced may focus, for example, on evaluating different seasonal operational parameters, connections to national power grids, and inputs to the interconnection from different power plants.

6. Evaluation of potential linkage between grid interconnection and the addressing of **global/regional environmental concerns**. This activity would include, for example, evaluating the conditions under which a grid interconnection would yield sufficient environmental benefits to qualify for partial funding by funds such as the Global Environmental Facility. The degree to which grid interconnections are developed so as to demonstrably protect or enhance the environment by, for example, protecting or enhancing biodiversity, reducing overall regional greenhouse gas emissions, or reducing the emissions of local and regional pollutants and their impacts, may help to open the door to funding alternatives otherwise unavailable.

7. Evaluation of **institutional/regulatory environmental issues** associated with grid interconnections. A concerted effort on the part of the countries involved will be required to

[66] The provision of technical materials and training on topics related to grid interconnection was suggested by members of the DPRK delegation during the Third Grid Workshop.

evaluate options for multilateral management of environmental aspects of power lines, including coming to an agreement on codes and standards to be met in line construction and operation. This will require detailed sharing between country representatives of applicable national laws and regulations, comparison of those laws and regulations with those from other countries and with international guidelines, and, ultimately, deciding upon what set of common codes and practices to be implemented for the grid connection. Other possibilities that might be considered include the establishment of international nature preserves in border areas where transmission lines pass through (augmenting, for example, national wildlife refuges).

8. Collaborative preparation of one or more regional **proposals to the Global Environment Facility** (GEF) to advance research the likely environmental characteristics of a state-of-the-art grid interconnection, and, if appropriate, to fund the implementation of such a grid interconnection. The demonstration, through the project, of innovative application of engineering concepts for the preservation of biodiversity—in addition to greenhouse gas emissions benefits—could provide a major advantage in seeking GEF funding.

9. Collaborative, multi-national work to develop a **policy constituency** for Northeast Asia grid interconnections. This would include making presentations on findings of the Grid Workshops and of "next steps" activities in capital cities in Northeast Asia and elsewhere, as well as making presentations at relevant technical workshops (such as the 8th International Symposium on Environmental Concerns in Rights-of-Way Management, to be held in Our next Symposium (ROW 8) will be held in Saratoga Springs, NY, USA, from September 12-16, 2004[67]).

As noted by Dr. Sergei Podkovalnikov during the Third Grid Workshop, many (though not all) of the above "Next Steps" will be facilitated by consensus on the most practical options—locations, transfer capacity, and other parameters—for transmission interconnections in the region. Early collaborations to agree on one or a set of proposals to be subjected to advanced study by multi-national research teams would therefore be in order.

### *9.3. Brief Review of Steps in Power Line Planning*

A grid interconnection itself is a very significant undertaking, requiring detailed planning in a number of different areas. A brief list of some of the steps required is provided below, with even more abbreviated indications of where environmental concerns are likely to come into the planning process.

- Economic pre-feasibility study (could include an evaluation of the cost of regional pollution abatement through a grid interconnection).
- Technical pre-feasibility study (including study of alternatives designed to maximize net environmental benefits).
- Charting of candidate interconnection routes and selection of one or a few alternatives for further study (including consideration of routings emphasizing environmental protection)

[67] See, for example, http://www.esf.edu/row8.

- Full feasibility study (technical, economic, environmental) on one or more interconnection alternatives.
- Full Environmental Impact Study for one or more interconnection alternatives.
- Selection and arrangement of financing for interconnection infrastructure (environmental considerations may play a role in financing, as noted above).
- Advanced technical design of infrastructure (including environmental protection infrastructure)
- Construction of infrastructure (including environmental monitoring during construction, and building of environmental protection infrastructure).
- Design and construction of any new power plants needed to feed electricity to the interconnection (each of which will have its own environmental considerations to include).
- Advanced design and implementation of operational protocols for the interconnection (including those designed to enhance environmental performance).

This overview has been provided to indicate that environmental issues must be an integral part of nearly all steps in the planning of grid interconnections. In some countries, significant capacity building will likely be needed so that researchers and officials from those countries can work effectively with counterparts on environmental issues associated with grid interconnections.

### ***9.4. Suggestions for Follow-up***

The Third Grid Workshop is designed to build on the results of the First and Second Workshops on Northeast Asia Power Grid Interconnections, as well as on the several national, bilateral, and multi-lateral cooperation initiatives on grid interconnection that have been started in recent years. The Third Grid Workshop's focus on the environmental dimensions of grid interconnections is intended to help researchers to bring these issues into the discussion of grid interconnection options. Immediate follow-up options designed to address and implement some of "next steps" described above, and discussed during the Third Grid Workshop, could include formalizing a network of researchers (with a secretariat somewhere in the region, for example), moving forward on designing and compiling a common database for grid interconnection modeling, fund-raising (and proposal preparation) to acquire resources for collaborative research and modeling, and arrangement of expert missions and study tours for individuals and groups from some countries. Groups carrying out any of these options should do so in communication, and, if practical, in collaboration with, groups already working in the field. Groups to coordinate with include those carrying out bilateral studies of grid interconnection (ROK/DPRK, ROK/RFE, and others), as well as study groups organized by ESCAP[68], and the NEAREST (North East Asian Region Electrical System Ties) group organized by the Korea Electrotechnology Research Institute and its partners.

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[68] The United Nations Economic and Social Commission for Asia and the Pacific. See, for example, http://www.unescap.org/unis/press/2003/apr/g_03_03.asp.

### ***9.5. Conclusion***

As noted in the introduction, this paper has not been designed to provide an exhaustive list of all possible environmental costs and benefits of grid interconnection, nor is it intended to indicate the specific costs and benefits that might accrue to grid interconnections in Northeast Asia. Rather, it has been designed to identify broad categories of impacts for further study by experts from the Northeast Asia region, and to indicate some of the key linkages between environmental, technical, and economic issues associated with grid interconnections. It is hoped that this overview has benefited those attending the Third Grid Workshop by offering a framework to address environmental issues, and will serve as an overall guide to those using the other papers prepared for the Workshop.

## Annex A: Annotated Links to Other Information

In addition to the World-wide Web links provided as references in the individual sections of this paper, the following list of links to information relating to the environmental performance of grid interconnections may be of use. Note that this listing is not intended to be exhaustive in any way, nor have the authors of this paper verified the information provided on these web sites.

http://www.energy.ca.gov/pier/energy/energy_landuse.html (land use implications of energy generation, distribution, and use, with some text and links on transmission lines and ways to reduce at least distribution impacts with wildlife).

http://www.adb.org/Documents/Resettlement_Plans/PRC/Hebei_Zhanghewan/default.asp (Index for ADB document providing the PRC: Hebei Zhanghewan Pumped Storage Project Resettlement Action Plan, including several sub-sections related to environmental impacts.

http://www.ebrd.com/enviro/index.htm (EIA summaries for transmission interconnection in Macedonia/Bulgaria from EBRD)

http://www.geni.org/energy/library/technical_articles/transmission/IntlGridandEnvironment.html titled International High-Voltage Grids and Environmental Implications presents summaries of panel discussions from an IEEE workshop, including discussion of the environmental impacts of grid interconnections in several international contexts and discussion of a new "HVDC Light" technology for serving smaller remote loads and power stations.

## Annex B: Template for Collection of Data for Calculation of Environmental Performance of Grid Interconnection

This Annex consists of printouts from a draft workbook that includes templates for collection grid- and power-plant-related data that would likely be needed as inputs to modeling of the performance of grid interconnections. The workbook, with the file name "Grid_Data_Compilation_Template_2.xls", can be made available for review and modification. A number of the data items included in the workbook were identified by Sergei Podkovalnikov and other colleagues in a letter prepared following the 2nd Grid Workshop (2002).

The types of data included in the workbook will be needed for collaborative work on grid stability and economic modeling of an interconnection, as well as for preparing estimates of the environmental performance of grid links. Although these data collection templates are intended to cover most of the range of information needed for the modeling of grid interconnections, it is certainly understood that the types of data actually available will vary considerably by country, and the types of data needed will vary with the specific modeling application. This template will therefore need to be modified to fit different country and modeling situations. In addition, those reviewing the workbook should bear in mind that this is only a partial draft, and additional data items will doubtless need to be added.

It may be useful, prior to the rescheduled Third Grid Workshop, for country teams to fill out or to partially fill out the workbook, and bring it to the Third Grid workshop prepared to discuss the types of data needed for collaborative modeling. Note that one of the worksheets in the workbook is a long list of questions about the various data items included in the workbook, along with responses to those questions (some of them acted upon in this workbook draft) supplied by Sergei Podkovalnikov. Comments on the workbook from workshop participants and other reviewers would be most welcome, and should be sent to David Von Hippel at dvonhip@igc.org or david@nautilus.org.

**"General Parameters" Worksheet**

**COMPILATION OF DATA FOR COLLABORATIVE STUDY OF ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA**

**Prepared for the "Third Workshop on the Northeast Asia Power Grid Interconnection"**

**Rough Draft, Date Last Modified:** 4/15/2003
**Prepared by:** David Von Hippel (based in part on suggestions by S. Podkovalnikov)

**GENERAL PARAMETERS**

| | | |
|---|---|---|
| Country Name: | | |
| Cost/Performance Data Base Year | 2002 | |
| First Projection Year | 2010 | |
| Second Projection Year | 2020 | |
| Monetary Unit: | Won | [included here just as an example] |
| Monetary Unit Conversion: | 1000 | Won per $ |

# "Existing_Gen" Worksheet

**COMPILATION OF DATA FOR COLLABORATIVE STUDY OF ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA**

**Prepared for the "Third Workshop on the Northeast Asia Power Grid Interconnection"**

| | |
|---|---|
| **Rough Draft, Date Last Modified:** | 4/15/2003 |
| **Prepared by:** | David Von Hippel (based in part on suggestions by S. Podkovalnikov) |

**CAPACITY AND PERFORMANCE DATA FOR EXISTING ELECTRICITY GENERATION PLANTS**

Note: If heat rates at different fractions of full capacity at which the plant operates are not available, specify an average heat rate and/or a heat rate for operation at 100% of full capacity.

| Power Plant/Unit Name | Power Plant Type | Installed Capacity (MW) | Year Placed in Service | Power Plant Use | Location | Heat Rate (MJ LHV/kWh) at Fraction of Full Capacity: 25% | 50% | 75% | 100% | Capacity Factor in 2002 (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Plant 1 Unit 1 | Nuclear--LWR | | | Intermediate | | | | | | |
| | HFO-fired--Steam | | | Peaking | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Natural Gas--Stea | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |

# "New_Gen" Worksheet

**COMPILATION OF DATA FOR COLLABORATIVE STUDY OF ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA**

**Prepared for the "Third Workshop on the Northeast Asia Power Grid Interconnection"**

**Rough Draft, Date Last Modified:** 4/15/2003
**Prepared by:** David Von Hippel (based in part on suggestions by S. Podkovalnikov)

**CAPACITY AND PERFORMANCE DATA FOR NEW OR PROPOSED ELECTRICITY GENERATION PLANTS**

| Power Plant/Unit Name | Power Plant Type | Installed Capacity (MW) | Year Placed in Service | Power Plant Use | Location | Heat Rate (MJ LHV/kWh) at Fraction of Full Capacity: 25% | 50% | 75% | 100% | Target Capacity Factor (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| New Plant 1 Unit 1 | Nuclear--LWR | | | Baseload | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Natural Gas--Stea | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | HFO-fired--Steam | | | | | | | | | |
| | Nuclear--LWR | | | | | | | | | |

## "Existing_Gen_Costs" Worksheet

**COMPILATION OF DATA FOR COLLABORATIVE STUDY OF**
**ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA**

**Prepared for the "Third Workshop on the Northeast Asia Power Grid Interconnection"**

| | |
|---|---|
| **Rough Draft, Date Last Modified:** | 4/15/2003 |
| **Prepared by:** | David Von Hippel (based in part on suggestions by S. Podkovalnikov) |

**OPERATING COST DATA FOR**
**EXISTING ELECTRICITY GENERATION PLANTS**

| Power Plant/Unit Name | Power Plant Type | Variable Non-fuel Operating Cost (Won/MWh) | Variable Non-Fuel Operating Cost ($/MWh) | Fuel Cost in 2002 Won/GJ LHV) | Fuel Cost in 2002 $/GJ LHV) | Average Annual Fuel Cost Esc., 2002 to 2010 (%/yr) | Fuel Cost in 2010 $/GJ LHV) | Average Annual Fuel Cost Esc., 2010 to 2020 (%/yr) | Fuel Cost in 2020 $/GJ LHV) |
|---|---|---|---|---|---|---|---|---|---|
| Plant 1 Unit 1 | Nuclear--LWR | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - |
| 0 | Nuclear--LWR | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Other | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - |
| 0 | Nuclear--LWR | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - |
| 0 | Nuclear--LWR | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - |
| 0 | Nuclear--LWR | | $ - | | $ - | | $ - | | $ - |

## "New_Gen_Costs" Worksheet

**COMPILATION OF DATA FOR COLLABORATIVE STUDY OF**
**ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA**

**Prepared for the "Third Workshop on the Northeast Asia Power Grid Interconnection"**

| | |
|---|---|
| **Rough Draft, Date Last Modified:** | 4/15/2003 |
| **Prepared by:** | David Von Hippel (based in part on suggestions by S. Podkovalnikov) |

**CAPITAL AND OPERATING COST DATA FOR**
**NEW OR PROPOSED ELECTRICITY GENERATION PLANTS**

| Power Plant/Unit Name | Power Plant Type | Variable Non-fuel Operating Cost (Won/MWh) | Variable Non-Fuel Operating Cost ($/MWh) | Fixed Non-fuel Operating Cost (Won/kW) | Fixed Non-Fuel Operating Cost ($/kW) | Capital Cost (Won/kW) | Capital Cost ($/kW) | Fuel Cost in 2002 Won/GJ LHV) | Fuel Cost in 2002 $/GJ LHV) | Average Annual Fuel Cost Esc., 2002 to 2010 (%/yr) | Fuel Cost in 2010 $/GJ LHV) | Average Annual Fuel Cost Esc., 2010 to 2020 (%/yr) | Fuel Cost in 2020 $/GJ LHV) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| New Plant 1 Unit 1 | Nuclear--LWR | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |
| 0 | Nuclear--LWR | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Other | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |
| 0 | Nuclear--LWR | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |
| 0 | Nuclear--LWR | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |
| 0 | HFO-fired--Steam | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |
| 0 | Nuclear--LWR | | $ - | | $ - | | $ - | | $ - | | $ - | | $ - |

"Max_Load&Energy" Worksheet

# COMPILATION OF DATA FOR COLLABORATIVE STUDY OF ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA

**Prepared for the "Third Workshop on the Northeast Asia Power Grid Interconnection"**

**Rough Draft, Date Last Modified:** 4/15/2003
**Prepared by:** David Von Hippel (based in part on suggestions by S. Podkovalnikov)

## PEAK LOAD AND ELECTRICAL ENERGY DATA
## CURRENT AND FORECAST SYSTEM-WIDE AND AREA TOTALS

| | 2002 | 2010 | 2020 |
|---|---|---|---|
| System Maximal Load (MW) | | | |
| Date on Which Maximal Load Occurs | 15-Jul | 16-Jul | 17-Jul |
| System Electricity Demand (GWh) | | | |

| | Fraction of System Maximal Load (MW) by Control Area | | |
|---|---|---|---|
| | 2002 | 2010 | 2020 |
| [Control Area 1] | | | |
| [Control Area 2] | | | |
| [Control Area 3] | | | |
| [Control Area 4] | | | |
| [Control Area 5] | | | |
| [Control Area 6] | | | |
| [Control Area 7] | | | |
| [Control Area 8] | | | |
| [Control Area 9] | | | |
| [Control Area 10] | | | |
| [Control Area 11] | | | |
| [Control Area 12] | | | |
| [Control Area 13] | | | |
| [Control Area 14] | | | |
| [Control Area 15] | | | |
| [Control Area 16] | | | |
| [Control Area 17] | | | |
| [Control Area 18] | | | |
| [Control Area 19] | | | |
| [Control Area 20] | | | |
| Total of above | 0.00% | 0.00% | 0.00% |

## "Max_Load&Energy" Worksheet (Continued)

| | Fraction of Demand (GWh) by Control Area (Annual) | | | Fraction of Control Area Energy Demand (GWh) by Season: Winter | | | Fraction of Control Area Energy Demand (GWh) by Season: Spring | | | Fraction of Control Area Energy Demand (GWh) by Season: Summer | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2002 | 2010 | 2020 | 2002 | 2010 | 2020 | 2002 | 2010 | 2020 | 2002 | 2010 | 2020 |
| [Control Area 1] | | | | | | | | | | | | |
| [Control Area 2] | | | | | | | | | | | | |
| [Control Area 3] | | | | | | | | | | | | |
| [Control Area 4] | | | | | | | | | | | | |
| [Control Area 5] | | | | | | | | | | | | |
| [Control Area 6] | | | | | | | | | | | | |
| [Control Area 7] | | | | | | | | | | | | |
| [Control Area 8] | | | | | | | | | | | | |
| [Control Area 9] | | | | | | | | | | | | |
| [Control Area 10] | | | | | | | | | | | | |
| [Control Area 11] | | | | | | | | | | | | |
| [Control Area 12] | | | | | | | | | | | | |
| [Control Area 13] | | | | | | | | | | | | |
| [Control Area 14] | | | | | | | | | | | | |
| [Control Area 15] | | | | | | | | | | | | |
| [Control Area 16] | | | | | | | | | | | | |
| [Control Area 17] | | | | | | | | | | | | |
| [Control Area 18] | | | | | | | | | | | | |
| [Control Area 19] | | | | | | | | | | | | |
| [Control Area 20] | | | | | | | | | | | | |
| Total of above | 0.00% | 0.00% | 0.00% | | | | | | | | | |

| | Fraction of Demand (GWh) by Control Area (Annual) | | | Fraction of Control Area Energy Demand (GWh) by Season: Fall | | | Fraction of Control Area Energy Demand (GWh) by Season: Annual (Control Total) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2002 | 2010 | 2020 | 2002 | 2010 | 2020 | 2002 | 2010 | 2020 |
| [Control Area 1] | | | | | | | 0% | 0% | 0% |
| [Control Area 2] | | | | | | | 0% | 0% | 0% |
| [Control Area 3] | | | | | | | 0% | 0% | 0% |
| [Control Area 4] | | | | | | | 0% | 0% | 0% |
| [Control Area 5] | | | | | | | 0% | 0% | 0% |
| [Control Area 6] | | | | | | | 0% | 0% | 0% |
| [Control Area 7] | | | | | | | 0% | 0% | 0% |
| [Control Area 8] | | | | | | | 0% | 0% | 0% |
| [Control Area 9] | | | | | | | 0% | 0% | 0% |
| [Control Area 10] | | | | | | | 0% | 0% | 0% |
| [Control Area 11] | | | | | | | 0% | 0% | 0% |
| [Control Area 12] | | | | | | | 0% | 0% | 0% |
| [Control Area 13] | | | | | | | 0% | 0% | 0% |
| [Control Area 14] | | | | | | | 0% | 0% | 0% |
| [Control Area 15] | | | | | | | 0% | 0% | 0% |
| [Control Area 16] | | | | | | | 0% | 0% | 0% |
| [Control Area 17] | | | | | | | 0% | 0% | 0% |
| [Control Area 18] | | | | | | | 0% | 0% | 0% |
| [Control Area 19] | | | | | | | 0% | 0% | 0% |
| [Control Area 20] | | | | | | | 0% | 0% | 0% |
| Total of above | 0.00% | 0.00% | 0.00% | | | | | | |

## "Load_Shapes" Worksheet

## COMPILATION OF DATA FOR COLLABORATIVE STUDY OF ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA

**Prepared for the "Third Workshop on the Northeast Asia Power Grid Interconnection"**

| | |
|---|---|
| **Rough Draft, Date Last Modified:** | 4/15/2003 |
| **Prepared by:** | David Von Hippel (based in part on suggestions by S. Podkovalnikov) |

### CURRENT AND PROSPECTIVE LOAD SHAPES

| | |
|---|---|
| **Maximum Annual Load (MW), 2002:** | |
| **Maximum Annual Load (MW), 2010:** | |
| **Maximum Annual Load (MW), 2020:** | |

**Average Daily Load Shape (MW)**

| Hour | 2002 | 2010 | 2020 |
|---|---|---|---|
| 0:00 | | | |
| 1:00 | | | |
| 2:00 | | | |
| 3:00 | | | |
| 4:00 | | | |
| 5:00 | | | |
| 6:00 | | | |
| 7:00 | | | |
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| 18:00 | | | |
| 19:00 | | | |
| 20:00 | | | |
| 21:00 | | | |
| 22:00 | | | |
| 23:00 | | | |

**Average Daily Load Shape (% of Maximal Load)**

| Hour | 2002 | 2010 | 2020 |
|---|---|---|---|
| 0:00 | | | |
| 1:00 | | | |
| 2:00 | | | |
| 3:00 | | | |
| 4:00 | | | |
| 5:00 | | | |
| 6:00 | | | |
| 7:00 | | | |
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| 19:00 | | | |
| 20:00 | | | |
| 21:00 | | | |
| 22:00 | | | |
| 23:00 | | | |

**Average Annual Load Shape (MW)**

| Month | 2002 | 2010 | 2020 |
|---|---|---|---|
| Jan | | | |
| Feb | | | |
| Mar | | | |
| Apr | | | |
| May | | | |
| Jun | | | |
| Jul | | | |
| Aug | | | |
| Sep | | | |
| Oct | | | |
| Nov | | | |
| Dec | | | |

**Average Annual Load Shape (% of Maximal Load)**

| Month | 2002 | 2010 | 2020 |
|---|---|---|---|
| Jan | | | |
| Feb | | | |
| Mar | | | |
| Apr | | | |
| May | | | |
| Jun | | | |
| Jul | | | |
| Aug | | | |
| Sep | | | |
| Oct | | | |
| Nov | | | |
| Dec | | | |

## "Line_Costs_Losses" Worksheet

**COMPILATION OF DATA FOR COLLABORATIVE STUDY OF ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA**

**Prepared for the "Third Workshop on the Northeast Asia Power Grid Interconnection"**

**Rough Draft, Date Last Modified:** 4/15/2003
**Prepared by:** David Von Hippel (based in part on suggestions by S. Podkovalnikov)

### COSTS AND PARAMETERS FOR LARGEST DOMESTIC TRANSMISSION LINES

| | | | | | | |
|---|---|---|---|---|---|---|
| Highest Transmission Line Voltage | 765 | kV | | | | |
| Next-to-Highest Transmission Line Voltage (if highest not routinely used) | 500 | kV | | | | |
| Average Capital Cost per circuit-km for 765 kV Transmission Lines | | Won, or | $ - | | | |
| Average Capital Cost per circuit-km for 500 kV Transmission Lines | | Won, or | $ - | | | |
| Average Land Cost per km for 765 kV Transmission Lines | | Won, or | $ - | | | |
| Average Land Cost per km for 500 kV Transmission Lines | | Won, or | $ - | | | |
| Average Operating Cost per circuit-km-yr for 765 kV Transmission Lines | | Won, or | $ - | | | |
| Average Operating Cost per circuit-km-yr for 500 kV Transmission Lines | | Won, or | $ - | | | |
| **or, alternatively** | | | | | | |
| Average Operating Cost for 765 kV Transmission Lines, % of capital cost | | %/yr, or | 0 | Won, or | $ - | /circuit-km-yr |
| Average Operating Cost for 500 kV Transmission Lines, % of capital cost | | %/yr, or | 0 | Won, or | $ - | /circuit-km-yr |
| Typical conductor cross-section for 765 kV Transmission Lines | | $cm^2$ | | | | |
| Typical conductor cross-section for 500 kV Transmission Lines | | $cm^2$ | | | | |
| Typical conductor type for 765 kV Transmission Lines | | | | | | |
| Typical conductor type for 500 kV Transmission Lines | | | | | | |
| Average Losses per circuit-km for 765 kV Transmission Lines | | (% of load) | | | | |
| Average Losses per circuit-km for 500 kV Transmission Lines | | (% of load) | | | | |

# "Backbone_Parameters" Worksheet

## COMPILATION OF DATA FOR COLLABORATIVE STUDY OF ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA

**Prepared for the "Third Workshop on the Northeast Asia Power Grid Interconnection"**

**Rough Draft, Date Last Modified:** 4/15/2003
**Prepared by:** David Von Hippel (based in part on suggestions by S. Podkovalnikov)

## TECHNICAL PARAMETERS FOR LINES AND TRANSFORMERS ON EXISTING DOMESTIC TRANSMISSION BACKBONE

Please include data for lines of voltage 220 kV and higher (110 kV and higher in smaller systems)

### TRANSMISSION LINES

| Line # | From | To | Voltage (kV) | Length (km) | Number of Circuits | Linear Resistance (Ohms/km) | Shunt Admittance (Siemens/ km) |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
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| 49 | | | | | | | |
| 50 | | | | | | | |

## "Backbone_Parameters" Worksheet (Continued)

**TRANSFORMERS**

| Unit # | Location | Input Voltage (kV) | Output Voltage (kV) | Capacity (MVA) | Short-Circuit Reactivity (Units?) |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |
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## "Existing_Gen_Param" Worksheet

**COMPILATION OF DATA FOR COLLABORATIVE STUDY OF ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA**

**Prepared for the "Third Workshop on the Northeast Asia Power Grid Interconnection"**

| | |
|---|---|
| **Rough Draft, Date Last Modified:** | 4/15/2003 |
| **Prepared by:** | David Von Hippel (based in part on suggestions by S. Podkovalnikov) |

**TRANSMISSION-RELATED PARAMETERS FOR EXISTING ELECTRICITY GENERATION PLANTS CONNECTED THROUGH TRANSFORMERS OF 220 kV OR HIGHER (110 kV OR HIGHER IN SMALLER SYSTEMS)**

| Power Plant/Unit Name | | Power Plant Type | Reactive Capacity (MVAr) | Syn-chronous Reactivity (%) | Transient Reactivity (%) | Sub-Transient Reactivity (%) |
|---|---|---|---|---|---|---|
| Plant 1 Unit 1 | | Nuclear--LWR | | | | |
| | 0 | HFO-fired--Steam | | | | |
| | 0 | HFO-fired--Steam | | | | |
| | 0 | Nuclear--LWR | | | | |
| | 0 | HFO-fired--Steam | | | | |
| | 0 | HFO-fired--Steam | | | | |
| | 0 | HFO-fired--Other | | | | |
| | 0 | HFO-fired--Steam | | | | |
| | 0 | HFO-fired--Steam | | | | |
| | 0 | Nuclear--LWR | | | | |
| | 0 | HFO-fired--Steam | | | | |
| | 0 | HFO-fired--Steam | | | | |
| | 0 | Nuclear--LWR | | | | |
| | 0 | HFO-fired--Steam | | | | |
| | 0 | HFO-fired--Steam | | | | |
| | 0 | Nuclear--LWR | | | | |

# "Backbone_Compensators" Worksheet

## COMPILATION OF DATA FOR COLLABORATIVE STUDY OF ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA

**Prepared for the "Third Workshop on the Northeast Asia Power Grid Interconnection"**

**Rough Draft, Date Last Modified:** 4/15/2003
**Prepared by:** David Von Hippel (based in part on suggestions by S. Podkovalnikov)

## TECHNICAL PARAMETERS FOR COMPENSATORS ON EXISTING DOMESTIC TRANSMISSION BACKBONE

Please include data for lines of voltage 220 kV and higher (110 kV and higher in smaller systems)

| Capacitor # | Capacitor Type | Location | Reactive Capacity (MVAr) | Voltage (kV) | Current (Maximum Amperes) |
|---|---|---|---|---|---|
| 1 | Synchronous VAR Compensators | | | | |
| 2 | Synchronous VAR Compensators | | | | |
| 3 | Synchronous VAR Compensators | | | | |
| 4 | Synchronous VAR Compensators | | | | |
| 5 | Synchronous VAR Compensators | | | | |
| 6 | Synchronous VAR Compensators | | | | |
| 7 | Synchronous VAR Compensators | | | | |
| 8 | Synchronous VAR Compensators | | | | |
| 9 | Synchronous VAR Compensators | | | | |
| 10 | Synchronous VAR Compensators | | | | |
| 11 | Synchronous VAR Compensators | | | | |
| 12 | Synchronous VAR Compensators | | | | |
| 13 | Synchronous VAR Compensators | | | | |
| 14 | Synchronous VAR Compensators | | | | |
| 15 | Synchronous VAR Compensators | | | | |
| 16 | Synchronous VAR Compensators | | | | |
| 17 | Synchronous VAR Compensators | | | | |
| 18 | Synchronous VAR Compensators | | | | |
| 19 | Synchronous VAR Compensators | | | | |
| 20 | Synchronous VAR Compensators | | | | |
| 21 | Synchronous VAR Compensators | | | | |
| 22 | Synchronous VAR Compensators | | | | |
| 23 | Synchronous VAR Compensators | | | | |
| 24 | Synchronous VAR Compensators | | | | |
| 25 | Synchronous VAR Compensators | | | | |
| 26 | Synchronous VAR Compensators | | | | |
| 27 | Synchronous VAR Compensators | | | | |
| 28 | Synchronous VAR Compensators | | | | |
| 29 | Synchronous VAR Compensators | | | | |
| 30 | Synchronous VAR Compensators | | | | |
| 31 | Synchronous VAR Compensators | | | | |
| 32 | Synchronous VAR Compensators | | | | |
| 33 | Synchronous VAR Compensators | | | | |
| 34 | Synchronous VAR Compensators | | | | |
| 35 | Synchronous VAR Compensators | | | | |
| 36 | Synchronous VAR Compensators | | | | |
| 37 | Synchronous VAR Compensators | | | | |
| 38 | Synchronous VAR Compensators | | | | |
| 39 | Synchronous VAR Compensators | | | | |
| 40 | Synchronous VAR Compensators | | | | |
| 41 | Synchronous VAR Compensators | | | | |
| 42 | Static VAR Compensators | | | | |
| 43 | Synchronous VAR Compensators | | | | |

## "Power_at_Nodes" Worksheet

**COMPILATION OF DATA FOR COLLABORATIVE STUDY OF ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA**

**Prepared for the "Third Workshop on the Northeast Asia Power Grid Interconnection"**

**Rough Draft, Date Last Modified:** 4/15/2003
**Prepared by:** David Von Hippel (based in part on suggestions by S. Podkovalnikov)

**ACTIVE AND REACTIVE POWER OF EQUIVALENT LOAD NODES (MAXIMUM LOADS)**

| Node # | Location | Active Power (MW) | Reactive Power (MVAr) |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
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# "Env_Impacts_Gen" Worksheet

**COMPILATION OF DATA FOR COLLABORATIVE STUDY OF ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA**

**Prepared for the "Third Workshop on the Northeast Asia Power Grid Interconnection"**

| | |
|---|---|
| **Rough Draft, Date Last Modified:** | 4/15/2003 |
| **Prepared by:** | David Von Hippel (based in part on suggestions by S. Podkovalnikov) |

## ENVIRONMENTAL EMISSIONS AND IMPACTS FROM POWER PLANTS: AIR POLLUTANTS, WATER POLLUTANTS, SOLID, AND NUCLEAR WASTES

### Emission Factors for Existing Generation

| | | Air Pollutant Emissions (kg/GJ LHV) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Power Plant/Unit Name | Power Plant Type | Carbon Dioxide | Sulfur Dioxide | Nitrogen Oxides | Particulate Matter (PM10) | Non-Methane Volatile Organic Componds | Methane | Liquid Wastes (kg solids/GJ LHV) | Fly and Bottom Ash (kg/GJ NHV) | Low-level Nuclear Wastes ($m^3$ per GWhe) | High-level Nuclear Wastes ($m^3$ per GWhe) | Nuclear Spent fuel (kg heavy metal per GWhe) | Land Area Needs for Power Plant (ha/MW) |
| Plant 1 Unit 1 | Nuclear--LWR | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | Nuclear--LWR | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | HFO-fired--Other | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | Nuclear--LWR | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | Nuclear--LWR | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | Nuclear--LWR | | | | | | | | | | | | |

**NOTE: IF AVAILABLE, IT MAY BE USEFUL FOR SOME MODELING TASKS TO HAVE EMISSION FACTORS DIFFERENTIATED BY FRACTION OF FULL LOAD AT WHICH A PLANT OPERATES (FOR EXAMPLE, TO HAVE DIFFERENT EMISSION FACTORS FOR PLANTS OPERATING AT 50, 75, AND 100 PERCENT OF RATED LOAD).**

### Emission Factors for New Generation

| | | Air Pollutant Emissions (kg/GJ LHV) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Power Plant/Unit Name | Power Plant Type | Carbon Dioxide | Sulfur Dioxide | Nitrogen Oxides | Particulate Matter (PM10) | Non-Methane Volatile Organic Componds | Methane | Liquid Wastes (kg solids/GJ LHV) | Fly and Bottom Ash (kg/GJ NHV) | Low-level Nuclear Wastes ($m^3$ per GWhe) | High-level Nuclear Wastes ($m^3$ per GWhe) | Nuclear Spent fuel (kg heavy metal per GWhe) | Land Area Needs for Power Plant (ha/MW) |
| New Plant 1 Unit 1 | Nuclear--LWR | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | Nuclear--LWR | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | HFO-fired--Other | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | Nuclear--LWR | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | Nuclear--LWR | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | HFO-fired--Steam | | | | | | | | | | | | |
| 0 | Nuclear--LWR | | | | | | | | | | | | |

## "Env_Impacts_fuel_cycle" Worksheet

**COMPILATION OF DATA FOR COLLABORATIVE STUDY OF ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA**

**Prepared for the "Third Workshop on the Northeast Asia Power Grid Interconnection"**

**Rough Draft, Date Last Modified:** 4/15/2003
**Prepared by:** David Von Hippel (based in part on suggestions by S. Podkovalnikov)

## ENVIRONMENTAL IMPACTS FROM OTHER FUEL CYCLE ACTIVITIES RELATED TO POWER GENERATON

### Natural Gas

| | | |
|---|---|---|
| Average gas losses for gas consumed in power plants | | % of consumption |
| Average gas consumed in gas delivery to power plants | | % of consumption |

**Average Emission Factors for Natural Gas Extraction/Delivery (kg/GJ gas delivered to power plants)**

| Pollutant | Gas Extraction (Production) | Gas Delivery |
|---|---|---|
| Carbon Dioxide | | |
| Sulfur Dioxide | | |
| Nitrogen Oxides | | |
| Non-methane Hydrocarbons | | |
| Methane | | |

### Oil Products

| | | |
|---|---|---|
| Average oil losses for oil consumed in power plants | | % of consumption |
| Average oil consumed in oil delivery to power plants | | % of consumption |

**Average Emission Factors for Oil Extraction/Refining/Delivery (kg/GJ oil delivered to power plants)**

| Pollutant | Oil Extraction (Production) | Oil Refining | Oil Delivery |
|---|---|---|---|
| Carbon Dioxide | | | |
| Sulfur Dioxide | | | |
| Nitrogen Oxides | | | |
| Non-methane Hydrocarbons | | | |
| Particulate Matter | | | |
| Methane | | | |

## "Env_Impacts_fuel_cycle" Worksheet (Continued)

**Coal**

Average coal losses for coal consumed in power plants [ ] % of consumption
Average energy consumed to transport coal to power plants [ ] [specify fuel and consumption per GJ coal used in power plants]

**Average Emission Factors for Coal Extraction/Processing/Delivery (kg/GJ coal delivered to power plants)**

| Pollutant | Coal Extraction (Production) | Coal Processing | Coal Transport/ Delivery |
|---|---|---|---|
| Carbon Dioxide | | | |
| Sulfur Dioxide | | | |
| Nitrogen Oxides | | | |
| Non-methane Hydrocarbons | | | |
| Particulate Matter | | | |
| Methane | | | |
| Solid Wastes | | | |

**Nuclear**

Average energy consumed to produce nuclear fuel for power plants [ ]
[specify fuel and consumption per GWhe nuclear power produced (or per unit fuel input)]

**Average Emission Factors for Nuclear Fuel Extraction/Preparation (kg/GWhe generated)**
**[May need to use other units for emissions]**

| Pollutant | Uranium Extraction (Production) | Uranium Processing | Fuel Fabrication |
|---|---|---|---|
| Carbon Dioxide | | | |
| Sulfur Dioxide | | | |
| Nitrogen Oxides | | | |
| Non-methane Hydrocarbons | | | |
| Particulate Matter | | | |
| Methane | | | |
| Solid Wastes | | | |

## "Env_Impacts_power_line" Worksheet

**COMPILATION OF DATA FOR COLLABORATIVE STUDY OF ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA**

**Prepared for the "Third Workshop on the Northeast Asia Power Grid Interconnection"**

**Rough Draft, Date Last Modified:** 4/15/2003
**Prepared by:** David Von Hippel (based in part on suggestions by S. Podkovalnikov)

**ENVIRONMENTAL IMPACTS FROM POWER LINE CONSTRUCTION AND OPERATION**

**Power Line Right-of-Way**

| Type of Power Line | Voltage | Reguired Right-of-way width (meters) | Descriptions of other requirements for construction of power line | Procedures for maintenance of power lines (including vegetation and erosion control) | Electromagnetic Field Strength (kV/m) |
|---|---|---|---|---|---|
| | 765 | | | | |
| | 500 | | | | |

**Descriptions of other qualitative or quantitative impacts of power lines of the type that would be used for an interconnection with a grids from nearby countries, including impacts from construction and operation, and impacts specific to the area through which the power lines would pass.**

## "Questions" Worksheet

# COMPILATION OF DATA FOR COLLABORATIVE STUDY OF ELECTRIC POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA

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## QUESTIONS FOR REVIEWERS ON CONTENT OF THIS WORKBOOK

**Note: "SP Response" denotes (sometimes summarized) responses to these questions from Sergei Podkovalnikov (3/9/03)**

| | |
|---|---|
| 1 | Are the types of power plants included in the selection menus in the "Existing Gen" and "New Gen" worksheets an appropriate classification for these purposes? SP Response: Add Cogeneration. |
| 2 | Is there a lower limit of the size of power plants that should be included in the list (for example, over 50 MW, though the limit could vary by country)? SP Response--probably not. |
| 3 | Is it useful to include a designator such as "baseload", "intermediate", or "peaking", and if so, are these three designators sufficient? SP Response--may be useful, but may be redundant with capacity factor. |
| 4 | Should the power plant location be specified by the name of the nearest town, by latitude/longitude, either, or both? SP response: not necessary. |
| 5 | Is the plant heat rate as a function of fraction of operating capacity a used and useful parameter in this analysis? SP Response: Useful, but possibly hard to obtain. |
| 6 | Into how many different areas should maximal load and electrical energy use be divided? Should the divisions be by power control area or by location (for example, by province)? SP Response: Depends on Modeling application and system studied. |
| 7 | Would it be useful to provide tables in the "Max_Load&Energy" workbook that calculated the load and energy by area, based on the percentages supplied? SP Response: Yes--See Tables 5-9 in InputData.doc. |
| 8 | Are daily and yearly load shapes more typically specified in MW or as a percent of maximal loading (both are now included)? SP Response: In RF, daily load shapes typically a fraction of maximum, and yearly load shapes are typically in MW, though both can be OK. |
| 9 | Does the daily load curve need to be specified on a time scale finer than one hour? SP response: No |
| 10 | Does the annual load curve need to be specified on a time scale finer than one month? SP response: No |
| 11 | Are the cost units typically used for the capital and operating costs of transmission lines as indicated? SP Response: Operating cost of transmission lines in Russia are usually given in percent of capital cost. |
| 12 | Are the units for conductor cross section typically used for transmission lines as indicated? Are there other types of information needed to adequately describe transmission lines for the purposes of modeling? SP Response: Wire cross-section is typically used for transmission lines. Other information requirements depend on the modeling task. For optimization of capacity mix and transfer capacity of transmission lines is being solved for, data [such as supplied in another file by SP] is needed. If power system analysis is being carried out, resistance and reactance of transmission lines, reactive power generated by transmission lines, and other parameters are also required. |
| 13 | Are the units for transmission line losses those that are typically used? If not, what units are typically used? SP Response: This depends on the modeling task. For example, losses as percentage of power flow are sufficient for the first task indicated in [SP response to question 12]. Losses are calculated based on parameters of transmission lines and power flows [for power system analysis]. |
| 14 | Are the units for linear resistence for transmission lines correct ("Backbone_Parameters" worksheet)? SP Response: Yes. |

## "Questions" Worksheet (Continued)

| | |
|---|---|
| 15 | What are the units for shunt admittance for transmission lines ("Backbone_Parameters" worksheet)? SP Response: Simens (S) per km. |
| 16 | I am not at all sure that I have the "reactivity" parameters that are needed for existing generation ("Existing_Gen_Param" worksheet) correct. Please correct the parameters if they are wrong. What are the correct units for the (correct) parameters? SP Response: Synchronous, transient and sub-transient reactivity parameters are correct and measured in %. I do not quite understand you what is "capacity reactivity". Perhaps you mean reactive capacity of generating unit. It is measured in kVAr or MVAr. |
| 17 | Is the selection list of different types of capacitors adequate ("Backbone_Capacitors" worksheet)? Should the different types of capacitors be listed separately (for example, in separate columns)? SP Response: What you call "capacitors" in the "Backbone_Capacitors" worksheet I would call "compensators". These are quite different things. |
| 18 | Are the units "Farads" typical for capacitors of the size used on transmission networks, or are different units more typical? Are different units used for the different types of capacitors? SP Response: Reactive capacity is typically used. It is measured in kVAr or MVAr. Some other parameters are also used (voltage, current, etc.) |
| 19 | Approximately how many power nodes ("Power_at_Nodes" worksheet) are typically needed for modeling, and how are they defined? Are they related to points on the transmission backbone, and are the data used for power and reactive power at nodes typically substation load data? Are the power data needed maximum or average power? SP Response: Nodes have to be defined considering particular [modeling] task and power system. Parts of power system having weak connections with other parts can be presented as separate nodes. Maximum power loads are needed. |
| 20 | How are locations for nodes typically defined (or how should they be defined or otherwise identified for this exercise)? SP Response: Nodes are defined based on the model used. Their locations conventionally do not have much physical sense. See also #s 6 and 19. |
| 21 | Are the units included for active and reactive power MW, or something different? SP Response: Active power is measured in MW, and reactive power is measured in MWAr [Should the latter be MVAr?]. |
| 22 | Is it necessary (in the "Env_Impacts_Gen" worksheet) to differentiate emission factors by capacity factor (similar to the treatment of heat rates) for power plants? SP Response: Difficult to obtain differentiated emission factors. |
| 23 | What are standard units of measure and standard conditions of measurement (in the "Env_Impacts_power_line" worksheet) of electromagnetic fields from power line operation)? SP Response: measured in kV/m. |
| 24 | Are there other environmental impacts of, or standards for operation of, power lines that are not yet reflected in this workbook? SP Response: In general looks good, ask Prof. Koshcheev for additional input. |

## "Menus" Worksheet

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**LISTS FOR PULL-DOWN SELECTION BOXES**

| Power Plant Types | Power Plant Use | Capacitor Type |
|---|---|---|
| Nuclear--LWR | Baseload | Synchronous VAR Compensators |
| Nuclear--Other | Intermediate | Static VAR Compensators |
| Coal-fired--Steam | Peaking | Capacitor Banks |
| Coal-fired--IGCC | | Reactors |
| HFO-fired--Steam | | |
| HFO-fired--Other | | |
| Natural Gas--Steam | | |
| Natural Gas--Comb. Turbine | | |
| Natural Gas--Comb. Cycle | | |
| Natural Gas--Other | | |
| Cogeneration--Coal-fired | | |
| Cogeneration--Gas-fired | | |
| Hydroelectric | | |
| Pumped-Storage | | |