7. Environmental Aspects of Grid Interconnection

7.1. Introduction

Construction and operation of transmission grid interconnections, and the power plants that feed them, have impacts—both positive and negative—on the local, and sometimes regional and global environments. In addition, transmission grid interconnections will affect the generation of electricity in the receiving country, and also, possibly, the production and use of other fuels. Evaluating and accounting the full-fuel-cycle environmental impacts of grid interconnections is an important element of the overall process of evaluating grid interconnection opportunities. 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 in general than technical, economic, and (often) political issues. In the case of grid interconnections in developing regions, 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[115].

7.2. Overview of Potential Environmental Benefits and Costs of Grid Interconnections

Most of the potential classes of environmental benefits of grid interconnections are treated in more detail in later sections of this Chapter. 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. Major air pollutant emission benefits therefore accrue overall (counting all the countries in the interconnection project) if the emissions from the generation that is used with the interconnection in place is less than the emissions that would have been produced in the absence of the interconnection. Where hydroelectric generation, for example, provides export power through an interconnection and displaces exist-

115 Much of the text in this Chapter was adapted from D. F. Von Hippel and J. H. Williams (2003), *Environmental Issues for Regional Power Systems in Northeast Asia*. Prepared for the Third Workshop on Northeast Asia Power Grid Interconnections, September 30 - October 3, 2003, Vladivostok, Russian Federation , and dated 12/2003. Available as *http://nautilus.org/archives/energy/grid/2003Workshop/Env_Issues_DVH_JW_final_pdf.PDF.*

ing or planned fossil-fueled power plants in the importing country, net emissions benefits will occur in most cases. The net air pollutant emissions benefits or costs for individual countries depend on which power plants run more, or less, in the presence of the interconnection, and where those plants are located.

- **Water pollution** impacts, including erosion and water pollutants produced as a result of power line construction and operation, and incremental water pollution from power plant construction, power generation, and fuel extraction/storage. As with air pollutant emissions, on a net basis, overall water pollution impacts can show either a net cost or a net benefit for the interconnection project as a whole, or for the different countries and localities involved, depending on the specifics of how the project is configured, and what would energy facilities would have been built and operated had the interconnection not been built.
- **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 and/or power plant construction. Net solid waste benefits accrue to the project mostly if coal-fired power is displaced by hydro, renewable, or gas-fired power, which net solid waste costs will occur, overall, if coal-fired plants are built to fuel the production of power exported over the interconnection.
- **Land-use** impacts, including costs such as the restriction of uses of land through which a power line passes, and benefits such as potential avoided land-use impacts from electricity generation or fuel extraction facilities avoided by the use of an interconnection.
- **Wildlife/biodiversity** impacts, including costs such as the potential impacts of power line construction and operation on flora and fauna in the power line area, and benefits such as 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 (net costs of the interconnection project), and benefits through avoided human health impacts through avoided air and water pollution.

As is clear from even these brief discussions of classes of impacts, international 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 environmental benefits and costs of an interconnection project can occur—through impacts caused by the interconnection net of impacts avoided by the project relative to other means of providing the same energy services as the interconnection—include construction of the power line and related infrastructure, operation of the power line, construction and operation for the power plants feeding the grid interconnection (or plants that are avoided by the use of the line), impacts related to fuel supplies for power plants, and impacts related to power plant wastes.

7.3. Potential 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 result of their operation. The following subsections provide a review of the potential local, regional, and global air pollution impacts and benefits from grid interconnections, summarize how the net air pollutant emissions or emissions savings (and their impacts) of an interconnection might be assessed, and briefly presents potential strategies for maximizing air pollution benefits of a grid interconnection.

Detailed evaluation of air pollution impacts at each of these scales can be extremely complex, and many reports and, indeed, entire volumes, projects, and analytical tools have been dedicated to the evaluation of air pollutant emissions and impacts[116]. 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[117].

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.

116 David Von Hippel and Harry Vallack (2000), *Manual for Preparation of Emissions Inventories for Use in Modeling of Transboundary Air Pollution*. Prepared as a Part of UNDP/UN DESA Subregional Project RAS/92/461: "Energy, Coal Combustion and Atmospheric Pollution in Northern Asia", Final Draft: 30 May, 2000. See also RAINS-Asia (1999), *RAINS (Regional Air Pollution INformation and Simulation)-Asia*. The RAINS-Asia project is a joint effort by IIASA, the World Bank, and the Asian Development Bank. Information on the project is available from *http://www.iiasa.ac.at/Research/TAP/rains_asia/docs/rains.asia.html*.

(Principal Authors:)

117 Notable examples in this area focusing on the Northeast Asia region are the work of Dr. David Streets and Dr. Greg Carmichael, prepared for the Nautilus Institute ESENA (Energy, Security and the Environment in Northeast Asia) project. These include Gregory Carmichael and Richard Arndt (1997), *Baseline Assessment of Acid Deposition in Northeast Asia* (available as *http://nautilus.org/archives/papers/energy/CarmichaelESENAY1.pdf*), and David G. Streets (1997) *Energy and Acid Rain Projections for Northeast Asia* (available as *http://www.nautilus.org/archives/papers/energy/streetsESENAY1.html*). In addition, Dr. Streets prepared a paper entitled *Environmental Aspects of Electricity Grid Interconnection in Northeast Asia* for the First Northeast Asia Power Grid Interconnection Workshop (2001, available as *http://www.nautilus.org/archives/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.

- **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 below provide brief discussions of air pollutants related to grid interconnections and their impacts at each of these scales.

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. Emissions from other parts of the fuel cycle, including air pollutant impacts of line construction (including diesel exhaust and fugitive dust), are therefore mentioned, but not treated in any detail, as these impacts are relatively transient and of short duration. The focus below is therefore on air pollutant impacts of power system operation with and without a grid interconnection between nations.

7.3.1. Local air pollutant 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[118].

- **Carbon monoxide**, or CO, which results from incomplete combustion of carbon-based fuels. Carbon monoxide is typically a relatively minor component of emissions 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. 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. Even relatively low concentrations of CO in the air can 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.

118 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.

- **Sulfur oxides**, of which sulfur dioxide (SO_2), which is typically the major species in the broader class of sulfur oxides (SO_x, in general), 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. SO_x 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** (NO_x), principally NO and NO_2, 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 $NO_{x.}$ 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.
- **Volatile organic compounds**, or VOCs, are 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, 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. These and other individual VOC 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. 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.

- **Particulate matter**, also referred to as "particulates", "dust", or "smoke", and sometimes abbreviated TSP for Total Suspended Particulates, 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), and 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 (10×10^{-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, 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. 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.
- **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. The impacts of metals on the environment and on human health vary with the metal element (and sometimes compound) emitted, and how they are emitted—for example, as a part of particulate matter. Some metals are plant nutrients in low concentrations, but toxic in higher concentrations. Metals of concern in the environment include Lead, Arsenic, Boron, Cadmium, and Mercury, with human health

impacts ranging from central and peripheral nervous system effects to blood problems, carcinogenicity, and birth defects. Heavy metals are often retained in the bodies of animals, and "bioconcentrated" in the food chain, leading to high concentrations of heavy metals in animal species that are "top predators" (such as large carnivorous birds, fish, and mammals).

- **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. 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. The effects of radioactive emissions on human health have been documented[119]. 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 to be sufficient to contribute to these problems.

As possible configurations of grid interconnections often 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, in Northeast Asia, 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 (Republic of Korea), or the DPRK (Democratic Peoples' Republic of Korea) 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[120].

Grid interconnections that result in improved availability of electricity in specific areas, particularly in developing regions, 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, the grid interconnection may provide significant local health benefits[121].

119 For information on the Chernobyl accident, sources include *http://www.chernobyl.info/*, and *http://www.world-nuclear.org/info/chernobyl/inf07.htm*.

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

121 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 *Northeast Asia Power Grid Interconnection Workshop*, held in Vladivostok, the Russian Federation in 2003, underscores this potential benefit of grid interconnections in the Northeast Asia context. This paper is available as *http://www.nautilus.org/archives/energy/grid/2003Workshop/K_DPRK_2_PPR.pdf*.

7.3.2. Potential 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, arguably the major regional air pollution impact is acid precipitation, sometimes called "acid rain", which is a significant environmental issue in North America, Northern Europe, and Northeast Asia, though not yet a serious issue in other regions. 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[122].

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". While acid rain is the most frequently discussed pathway for these compounds to return to earth, nitrates and sulfate ions[123] (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 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[124]. 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[125].

122 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.

123 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^-).

124 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.

125 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.

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 can 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 regional 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, and emissions from as far away as the United Kingdom have contributed to acid rain and forest decline in Scandinavia[126].

A paper by Prof. Zhu Fahua prepared for the Third Northeast Asia Power Grid Interconnection 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[127].

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 a region. 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, and in most places where interconnections are contemplated will require capacity building, data sharing, and above all, extensive coordination in modeling efforts in order to obtain credible results.

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

126 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 the countries of Asia, provides an excellent resource for studies of the impacts of energy system changes on acid precipitation in Northeast Asia, and a model for other regions. 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.

127 Please see *http://www.nautilus.org/archives/energy/grid/2003Workshop/Environmental%20Impacts_Zhu_final2.pdf.*

indoor and local air pollutants, be causing changes in regional and even global climate[128]. 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"[129]. 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.

7.3.3. Global air pollution impacts

International electricity grid interconnections, 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 even across oceans. 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.

"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 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[130]. 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_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3),

128 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.

129 Quote from Menon *et al* article referenced above.

130 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.

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, concern arises from the potential *additional* global warming that may occur due to the rapidly increasing concentrations of heat-trapping greenhouse gases caused by human activities such as 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 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, and emissions of methane from coal mines is often also significant. 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[131].

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 is biomass decomposition in areas flooded for hydroelectric reservoirs. Decomposition of biomass in the flooded areas releases carbon dioxide, but more importantly, also results in the significant release of methane—the product of anaerobic decomposition of biomass. Hydro reservoirs can also change the fate of carbon-rich sediments that wash into rivers, perhaps rendering the carbon compounds in the sediments more likely to undergo methane producing anaerobic decomposition than to be degraded aerobically to carbon dioxide or incorporated into longer-lived soil carbon. This difference is very significant when the relative impacts of methane and CO_2 emissions on climate are considered, as methane has an impact on climate more than 20 times as strong, on a per-unit-mass basis, as CO_2. Some researchers have found net greenhouse

131 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) . 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).

gas emissions, expressed on CO2-equivalent basis per unit of electricity generated, for specific Brazilian hydroelectric reservoirs, to be many times larger, on an annual basis, than for natural gas-fired combined-cycle power plants. In the context of discussions of grid interconnections from Quebec, Canada to the Northeast United States, the following point was made[132].

> "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."

Based on research into methane production in hydroelectric reservoirs in Amazonia and other areas, Philip Fearnside of the Brazilian National Institute for Research in the Amazon concludes[133]:

> ". . . reservoirs become virtual methane factories, with the rise and fall of the water level in the reservoir alternately flooding and submerging large areas of land around the shore; soft green vegetation quickly grows on the exposed mud, only to decompose under anaerobic conditions at the bottom of the reservoir when the water rises again. This converts atmospheric carbon dioxide into methane, with a much higher impact on global warming than the CO_2 that was removed from the atmosphere when the plants grew."

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 globe. Particular examples of estimated 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.
- Changes in biodiversity and species distribution—all of the changes above have the potential to

132 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*.

133 As quoted in Patrick McCully (2004), *Tropical Hydropower is a Significant Source of Greenhouse Gas Emissions: A response to the International Hydropower Association*. International Rivers Network, December 2004, *http://www.irn.org/basics/conferences/cop10/pdf/TropicalHydro.12.08.04.pdf.* Original reference is P.M. Fearnside (2004) "Greenhouse gas emissions from hydroelectric dams: Controversies provide a springboard for rethinking a supposedly 'clean' energy source". *Climatic Change* 66. Please note that the authors of this Report have not independently checked the assessment of high methane emissions from hydroelectric reservoirs as provided by Fearnside—we simply note that net methane emissions should be estimated as a part of the environmental impact assessment process, and will likely differ substantially between hydroelectric projects and event between alternative designs for the same project.

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 may 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 (likely) 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 section 7.9 of this report.

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 noted risks to ecosystems and wildlife many thousands of kilometers away from the emissions source[134]:

News reports based on recent suggest that Trans-Pacific air pollutant transport is widespread in destinations, sources, and the types of pollutants involved[135]. Accurate quantitative estimates of the sources and receptors—and identification of the key species involved in Trans-Pacific air pollution—may be years or decades away, but this global environmental issue bears at least mention in forward-looking environmental assessments—particularly as the atmospheric conditions that carry trans-Pacific pollutants likely exist elsewhere on the globe. 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 long-distance transport.

134 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.

135 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*.

7.3.4. Requirements for calculation of net air pollution costs and benefits of a grid interconnection

A brief roster of the types of information and calculations that are likely to be required for the estimation of the air pollutant benefits and costs of a 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.
- 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.
- An assessment of how the interconnection will affect **non-electric fuel use**, if at all, including which types of fuels and devices (wood stoves or oil lamps, for example) will be affected, by how much per year, and where the devices are located.
- **Emission factors** for power plants and other fuel-using devices implicated in the interconnection. These factors will express the emissions of atmospheric pollutants in mass (or radiological) units per unit fuel consumed, or per unit of power output. 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. David Streets, in a paper originally prepared for the First Workshop on Power Grid Interconnection in Northeast Asia, provides a sample set of emission factors for power plants (and, in the case of biofuels, residential stoves) using different types of fuels[136]. These emission factors are expressed in terms of mass of emissions per unit of input fuel.
- 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.

136 David Streets (2001), *Environmental Aspects of Electricity Grid Interconnection in Northeast Asia*. Prepared for the First Workshop on Power Grid Interconnection in Northeast Asia Beijing, China, May 14-16, 2001, and available as *http://www.nautilus.org/archives/energy/grid/papers/streets.pdf*. Databases of emission factors are available from a number of sources, including the USEPA's "AP-42" compilation, the IPCC, and other sources. See Section 7.11 [CHECK] for sources for this topic.

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 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, estimates of other increased or avoided fuels use, emission factors, and impacts analyses noted above.

7.4. Impacts of Grid Interconnection on Water Pollution and Water Quality

To perhaps a greater extent than air pollution impacts, significant water pollution impacts—both benefits and negative impacts—of grid interconnections can come from construction and maintenance of power lines, as well as from the 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 a list of generic impacts that can be detailed more fully when an assessment of water pollution impacts of a specific grid interconnection is needed.

7.4.1. 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[137].

7.4.2. 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 many proposed developing-country grid interconnections are impacts related to hydroelectric power development. Hydroelectric dam construction may (likely will) result in significant at least 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 or coal fuels for power generation. Both routine (such as minor oil losses during transfers from ships to shore terminals) and accidental (such as pipeline "blowouts", or spills of oil or oil products resulting from tanker acci-

137 A case where the compaction of soils due to transmission line construction on the hydrology of wetland soils was noted is described in Public Service Commission of Wisconsin (1998), *PSC Overview Series, Environmental Impacts of Electric Transmission Lines.* Available as *http://psc.wi.gov/consumer/electric/cnstrenv/envirimp.pdf.*

dents) 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.

7.4.3. Preparing Estimates of Water Quality Impacts

The preparation of 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 in some instances be relatively straightforward. For these types of routine emissions, estimates of net generation (or avoided generation) by power plant or plant type are needed, as described above in the context of the estimate of net air pollutant emissions impacts. 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. 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.

7.5. Impacts of Interconnection on Generation of Solid and Hazardous Wastes

The third category of pollutant emissions considered in this Chapter 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.

7.5.1. Solid and hazardous wastes during interconnection construction and operation

The types and extent of solid and hazardous wastes produced during the construction and operation of a grid interconnection 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[138].

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.

7.5.2. 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) and heavy oils[139]. **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.

<u>Scrubber sludge</u> 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, though some, if handled correctly, can be recycled into industrially useful products.

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138 The Agency for Toxic Substances and Disease Registry (ATSDR) of the United States Center for Disease Control offers information including the emissions pathways, and sources of PCBs, the long-term retention of PCBs in the environment, and the concentration of PCBs in the food chain. ATSDR (2001), *ToxFAQs™ for Polychlorinated Biphenyls (PCBs)*. Available as *http://www.atsdr.cdc.gov/tfacts17.html*.

139 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.

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 of the most common design, at least)[140].

7.5.3. 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. These wastes by their physical nature change landscapes and thus the environment, potentially resulting in the displacement of animal species, changes in vegetation, and/or aesthetic impacts. Some mining wastes 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 large 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

140 A paper by Jungmin Kang prepared for the Third Northeast Asia Grid Interconnection 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 more detail nuclear power and nuclear waste issues associated with grid interconnections involving the ROK Please see *http://www.nautilus.org/archives/energy/grid/2003Workshop/Jungmin_KANG_final.pdf*.

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.

7.5.4. Estimating solid wastes costs and benefits of interconnections

Preparing estimates of net emissions of solid and hazardous waste resulting from an interconnection is relatively straightforward for some categories of 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 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 various types of radioactive wastes per unit of electricity produced in light-water reactors, for example, are available, and can be used to estimate the net impact of an interconnection on production of nuclear waste product[141].

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 transmission line towers being installed, the size of the tower 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. The net economic costs of managing

141 An example of a set of estimates of nuclear material "emission factors", originally derived from several sources, can be found in 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/archives/papers/energy/dvh_hayesNukeScenarios.pdf***.

solid wastes produced (or avoided) as a part of the interconnection project construction and/or operation are also a consideration to be addressed in interconnection project assessment and design.

7.6. Impacts of Grid Interconnection on Land Use

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 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.

7.6.1. Impacts of construction and operation of transmission lines on land use

The direct effects on land use caused by transmission lines and associated substations, conversion stations, and switchyards that would be part of an interconnection project 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 of the interconnection.

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 clearing required depends on the transmission line routing and the right-of-way width, which may vary from one locale to the next less the amount of land already cleared for existing rights-of-way to be shared by the transmission line (if any).

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.

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.

7.6.2. 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, with possible implications for the construction and operation of individual generating facilities within the interconnected system

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 an interconnection would be expected to submerge a minimum of 50,000 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, with associated impacts on those organisms (plants, animals, and humans) that depend on the river for their livelihoods.

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 7.6.1. 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.

7.6.3. 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—yielding net environmental benefits and costs—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 impacts 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, oil import terminals, and/or 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, even from one country to another, in the sense that the beneficiaries of the electricity supply/interconnection project can be quite different from those who bear the environmental consequences.

7.6.4. Preparing estimates of land-use benefits and costs of grid interconnection

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 estimation of the net land use impacts of interconnection will require, for both the interconnected case and the non-interconnected (reference) case:

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

In each case, the above information should emphasize collection of information on infrastructure whose timing of construction (or decommissioning) and/or capacity will differ between the cases considered. 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 of an interconnection 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 the interconnection.

7.7. Potential Impacts of Interconnection on Biodiversity and Wildlife

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"[142]. The impacts of grid interconnections on biodiversity and wildlife result from the impacts of the transmission lines themselves, 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

142 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.*

conductor design, and how the interconnection is operated and maintained. If interconnection 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.

7.7.1. Potential impacts of transmission lines on biodiversity and wildlife

The potential impacts of a grid interconnection on biodiversity and wildlife result from the interaction of species and their habitats with the physical features of the interconnection infrastructure 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 biodiversity indirectly by altering natural relationships and competitive balances.

The transmission right-of-way can entail direct conversion of significant amounts of habitat, as noted above, depending on the length of the interconnection line and the use of existing rights-of-way, if available. Regardless of the total magnitude of land altered, 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 natural 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—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.

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.

7.7.2. 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 a net benefit.

7.8. Potential Impacts of Grid Interconnections on Human Health

The net impact of grid interconnections on human health are a function of the direct health impacts of transmission lines and the indirect impacts of changes in generation and other fuel-cycle activities. 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 time, interconnection can lead to generation and fuel-cycle changes that can improve or worsen human health effects.

7.8.1. 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.

Human 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[143]. 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. Controlled laboratory tests and other epidemiological studies, however, 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.[144]

Studies indicate that the largest source of EMF exposures for many people are in the household and office, coming from house hold 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.

143 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.

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

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.

7.8.2. 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 with 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 above, coal-fired power plants emit sulfates, nitrogen oxides, and particulates (at levels that vary with fuel quality and the pollution control technology used in the plant, among other parameters), all of which are associated with significant impacts on the human respiratory and cardiovascular systems. Coal-fired power plants 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.

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

In many cases, the rules and regulations in force in the countries hosting the interconnection, and the similarities and differences between those rules, will shape the standards that the environmental performance of an interconnection must meet. Similarly, multinational funding agencies also mostly have their own rules for how to assess project environmental performance, as well as minimum performance standards. Environmental standards also have both legal and political aspects and ramifications.

7.9.1. National environmental regulations related to interconnection

As noted in Chapter 4 of this Report, the environmental impacts of the construction and maintenance of an international grid interconnection will likely be subject to at least two sets of potentially different environmental standards, codes and regulations. In addition, each country will have its own institutions responsible for environmental regulations in the power sector, and procedures for complying with those regulations. Agreements on how the environmental elements of the interconnection common to both or all countries involved in the project will be assessed, monitored, and regulated will be required among the participating countries, as well as among any participating financial institutions that have their own such requirements (see below). In general, the types of regulations that will or may need to be complied with by project sponsors, planners, contractors, and operators in the countries involved in the interconnection may include:

- Environmental Assessment regulations
- Air pollution regulations
- Water conservation and management regulations
- Soil conservation and managements regulations
- Ecological conservation and management regulations
- Human health and safety regulations, including occupational health and safety regulations
- Solid and toxic waste disposal regulations
- Wildlife (animals and plants) conservation and management regulations
- Regulations relating to national parks and wilderness areas
- Other regulations related to land use

A review of the existing laws in each country that pertain to the environmental aspects of the project is a necessary part of early project planning, followed by discussions between project parties regarding how, if at all, standards for the project will need to be adjusted to comply with national regulations[145].

7.9.1. Multinational lending institution environmental regulations and procedures

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 by Dr. James H. Williams, entitled "International Best Practices for Assessing and Reducing the Environmental Impacts of High-Voltage Transmission Lines"[146]. Dr. Williams' paper begins with a brief overview of the types of transmission line impacts described above, discusses widely-accepted approaches and methods for assessing and reducing transmission line impacts, reviews the environmental requirements relevant to transmission line projects set by the World Bank {International Bank for Reconstruction and Development, or IBRD) and the Asian Development Bank for Bank-funded

145 Four papers by authors from Northeast Asia prepared for the Third Workshop on Power Grid Interconnection in Northeast Asia, Vladivostok, Russia, September 30 - October 3, 2003. illustrate some of the various environmental laws and regulations in nations and in sub-national jurisdictions that can affect an interconnection project: "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; "Environmental, Technical, and Safety Codes, Laws and Practices Related to Power Line Construction in Russia", by Andrew S. Gerasimov; and "The Environment of, and Environmental Regulations in, the Russian Far East". These papers are available as *http://www.nautilus.org/archives/energy/grid/2003Workshop/Paper_suhmoon_final.pdf, http://www.nautilus.org/archives/energy/grid/2003Workshop/M_Zhao_PPR.pdf, http://www.nautilus.org/archives/energy/grid/2003Workshop/Gerasimov%20paper_final1.pdf, and http://www.nautilus.org/archives/energy/grid/2003Workshop/paper_sheingauz_final2.pdf, respectively.*

146 James 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, September 30 - October 3, 2003. Nautilus Institute Report, available as *http://www.nautilus.org/archives/energy/grid/2003Workshop/Env_Best_Practices_Williams_final.pdf.*

initiatives, describes, as a case study, the environmental 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.

Williams' summary of World Bank requirements and protocols regarding environmental assessment includes the following:

> "The procedures for obtaining Bank assistance depend on a number of variables, including the types of financial instruments or assistance sought, what organizations are involved on the borrower side, and the precise nature of the project. In general, the steps for completing the environmental component of loan applications includes the following steps, which are undertaken by a partnership of the borrower and the Bank's task team:

- Creation and approval of a Project Concept Document (PCD). 'The PCD defines the rationale for a proposed investment operation and …serves as the basis for a Bank decision to assist a borrower with project preparation.'
- Creation and approval of a Project Appraisal Document (PAD) '…which evolves from the PCD… and summarizes the task team's assessments of various aspects of the operation…The PAD serves as the basis for the Bank's appraisal.'
- Creation and approval of a Project Implementation Plan (PIP), which 'presents main project components, implementation plan, and arrangements for monitoring and evaluation.'
- Environmental Assessment (EA). This is the process by which environmental and social impacts are identified and avoided or mitigated.
- In some cases with significant potential environmental impacts, an Environmental Monitoring Plan (EMP) is required.

Specific guidance on Bank criteria and procedures, including those that apply to Environmental Assessment, are generally based on one of three kinds of internal Bank documents: Operational Policies (OPs), Bank Procedures (BPs), and Good Practices (GPs). These are found in *The World Bank Operational Manual* and in other Bank manuals and guides."

Williams notes that the World Bank Operational Manual includes a number of "Safeguard Policies", "…the purposes of which are to ensure that adverse environmental and social consequences of projects receiving Bank support are identified, minimized, and mitigated"[147]. Among those sections of the *Manual* identified as related to the potential environmental impacts of grid interconnections are:

- **Environmental Assessments**, for which three different main categories of requirements exist, depending on the scale of the project.

- **Natural Habitats**, specifying the World Bank's policy on conversion of natural habitats, and guidelines for involving local communities and others in habitat protection.

147 A World-wide Web version of the *World Bank Operational Manual* can be found at *http://wbln0018.worldbank.org/institutional/manuals/opmanual.nsf/textonly.*

- **Pest Management**, describing policies preferring the use of biological and environmental pest control techniques where needed in World Bank-funded projects.
- **Cultural Property**, discussing policies on the conversion of lands on which important cultural resources are found, including important natural aesthetic resources.
- **Involuntary Resettlement**, including a commitment to avoid involuntary resettlement whenever possible, and a requirement for thorough planning to mitigate the impacts of resettlement when unavoidable.
- **Forests**, identifying issues relating to forest conversion, which may at times be an element off the planning of an interconnection.
- **Projects in Disputed Areas**, describing the World Bank's policies for providing financing for projects that are built in areas disputed by two (or more) countries.

The World Bank's *Environmental Assessment Source Book* includes guidelines for conducting environmental assessments for various kinds of projects, along with recommendations regarding environmental "good practices"[148].

7.9.3. 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. Coordina-

148 World Bank (1999), *Environmental Assessment Source Book 1999*. World Bank, Washington, D.C., USA, 1999. A complete 1991 version of this work is available in 3 volumes as *http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/1991/07/01/000009265_3971126124401/Rendered/PDF/multi_page.pdf*, *http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/1991/08/01/000009265_3971126124405/Rendered/PDF/multi_page.pdf*, and, World Bank Technical Reference Papers numbers 139, 140, and 154, with PDF files providing annual updates in several years through 1999 also available on-line (search *http://www-wds.worldbank.org/* for "Environmental Assessment Sourcebook").

tion 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.

7.10. Summary and Conclusion

7.10.1. Potential environmental benefits and costs of grid interconnection

International electrical grid interconnections can offer a wide range of environmental benefits, but can also cause a wide range of environmental impacts. Environmental benefits—including reduced or avoided air pollutant emissions (including pollutants of local, regional, and global significance), reduced water pollution, reduced solid and hazardous wastes, reduced land-use impacts, reduced impacts on biodiversity and wildlife, and reduced impacts on human health—can be provided by the grid interconnection, but net environmental impacts in each of these categories can also occur as the result of the interconnection. In addition, a grid interconnection can provide net environmental benefits of one or (more likely) several types in some locations, while resulting in net environmental costs of one or (more likely) several types in other locations. A grid interconnection may, for example, reduce carbon dioxide and other emissions in a country importing power by reducing the use of coal-fired generating stations in that country, but the hydroelectric dams built to supply electricity in an exporting country may produce significant net methane emissions, reducing or even swamping any net greenhouse gas emissions benefits of the interconnection. An estimate of the significant environmental costs and benefits that will flow from a grid interconnection therefore requires a thorough and systematic study of all of the aspects of the interconnection, the electricity generation facilities feeding the interconnection, and the fuel chains feeding electricity generation, in all of the countries and areas within countries that may be affected by changes in energy sector activity or infrastructure brought about by the interconnection.

7.10.2. Strategies for enhancing environmental benefits and reducing environmental costs of grid interconnections

Even with many different environmental impacts (costs and benefits) to consider in potentially several different geographic areas for each interconnection projects, there are a number of general approaches that can be used in designing, planning, building and operating interconnections so as to increase net environmental benefits and reduce environmental costs and risks. These strategies include:

- Design interconnections so that power flows are dispatched in such a way that the use of the worst existing power plants (lowest efficiency, highest pollutant 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 and other environmental benefits. Actually decommissioning aging, inefficient, and polluting power generation facilities as electricity from an interconnection becomes available may be a way to help secure long-term emissions savings from an interconnection, though practical and political obstacles to such linked decommissioning are not unlikely. Planning and dispatching the interconnected system for environmental benefit will include the operation of the system so as to reduce the use of solid (especially coal) and liquid fuels, thereby reducing the environmental impacts of coal combustion, ash disposal, and coal mining, and reducing the probability of spills, leakage, and leaching of water pollutants resulting from fuel storage.

- Make sure that any fossil-fueled power plants whose use will increase as a result of the interconnection has stringent air pollutant emission controls, discharges thermal emissions to the air or to waters where the impacts of thermal emissions are negligible, maintains procedures for disposing of any solid wastes that prevent toxins from leaching to the environment, and, if possible, are located far from population centers or sensitive ecosystems.
- 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.
- 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, impacts on water resources, and impacts on aquatic habitats.
- Use existing roads and right-of-ways whenever possible when new power lines or transport access is need as part of the interconnection. Where new roads and right-of-ways are needed, design and construct them with care to avoid erosion and run-off. Choose any required new 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. Avoid the use of long-lived herbicides in right-of-way maintenance when less toxic alternatives can be employed. Use heavy machinery as sparingly as possible during power line construction and maintenance. Choose transmission tower designs taking into account the safety of both people and wildlife.
- Collect and make available thorough information about the environmental characteristics of the areas to be affected by the interconnection, including land uses. Conduct 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, demand-side management programs that reduce or eliminate the need for new capacity.
- In planning the interconnection and in preparing Environmental Impact Assessments, solicit input from a wide range of stakeholders, including local citizen groups from areas potentially environmentally affected by the project, national and local environmental protection agencies, and outside experts such as ecologists and wildlife biologists in academic institutions and environmental NGOs.

7.11. Resources for further analysis

7.11.1. References

Specific references for further information on this topic include:

- The longer report on the topic on which much of this Chapter is based, namely D. F. Von Hippel and J. H. Williams (2003), *Environmental Issues for Regional Power Systems in Northeast Asia*, and papers by other authors prepared for the Third Workshop on Northeast Asia Power Grid Interconnections, held September 30 - October 3, 2003, in Vladivostok, the Russian Federation and available from *http://www.nautilus.org/archives/energy/grid/2003Workshop/papers.html*
- World Bank (1999), *Environmental Assessment Source Book 1999*. See *http://lnweb18.worldbank.org/ESSD/envext.nsf/47ByDocName/* Tools Environmental Assessment Sourcebook and Updates for access to the chapters of this document. Note that the chapters touch upon many topics, including the interaction of economic and environmental analysis ("Chapter 4. Economic Analysis of Projects and Policies with Consideration of Environmental Costs and Benefits").
- African Development Bank (2000), *Environmental Review Procedures for Private Sector Operations of The African Development Bank Group*. Available from *http://www.afdb.org/psdu/environment/esap_private_sector_operations_pees_op_ration_secteur_prive/environmental_review_procedures_for_private_sector_operations_of_the_adb_group*.
- The United States Environmental Protection Agency offers a comprehensive set of source documents and databases for emission factors for all sorts of air pollutant-producing processes. The overall source document, called *AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources*, often referred to simply as "AP-42", is available through the "CHIEF" emissions factor clearinghouse, at *http://www.epa.gov/ttn/chief/ap42/*. Volume 2 of this compendium, which deals with mobile sources of air pollutants, is available from *http://www.epa.gov/otaq/ap42.htm*.
- The *IPCC Guidelines for National Greenhouse Gas Inventories* from the Intergovernmental Panel on Climate Change (IPCC), revised 1996 version, provides both methods and emission factors for estimating greenhouse gas emissions from a variety of human activities, including energy-sector emissions. In many instances, the "tier 1" or "tier 2 and 3" emission factors from this compilation are good starting estimates for the estimation of net emissions (or avoided emissions) from many activities related to interconnections. The three-volume *Guidelines* documents are available from *http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.*

Readers are also encouraged to consult the other references cited in footnotes throughout this Chapter.

7.11.2. Models and software systems for environmental analysis of power line impacts

In addition to the IPCC and World Bank Environmental Assessment documents provided above, the user may wish to consult the United States Environmental Protection Agencies "Technology Transfer Network Support Center for Regulatory Air Models" (SCRAM) web site (*http://www.epa.gov/ttn/scram/*) for information on (and, in some cases, working versions of) different type of models of air pollutant emissions, dispersion, and impacts on air quality (among other topics). Many other types of models are available from other, often commercial, sources.