Department of Economic and Social Affairs
Division for Sustainable Development

Multi-Dimensional Issues in International Electric Power Grid Interconnections

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DESA

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NOTE

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abbreviations

A	Ampere, or Amp
AC	Alternating current
ACE	Area control error
ACRS	Aluminum conductor steel reinforced
ADB	Asian Development Bank
ADB or AfDB	African Development Bank
AFUR	African Forum of Utility Regulators
ATC	Available transmission capacity
Btu	British Thermal Unit
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CDM	Clean Development Mechanisms
CHP	Combined Heat and Power, or cogeneration
CT	Current transformers
DC	Direct current
DESA	United Nations Department of Economic and Social Affairs
DSM	Demand-side management
EA	Environmental assessment
EDF	Electricité de France, the French national utility
EHV	Extra high voltage
EMF	Electromagnetic field
EPRI	Electric Power Research Institute, an organization of the electric utility industry in the United States
FACTS	Flexible AC transmission system
GDP	Gross domestic product
GHG	Greenhouse gas
GJ	Gigajoule; one billion (10^9) Joules
GW	Gigawatt; one billion (10^9) Watts
GWh	Gigawatt-hour; one billion (10^9) Watt-hours
Hz	Hertz (See Frequency in Glossary)
HVAC	High voltage alternating current
HVDC	High voltage direct current
HC	Hydrocarbons
I	Current
IIASA	International Institute for Applied Systems Analysis, located in Austria
IRP	Integrated resource planning
IPCC	Intergovernmental Panel on Climate Change
ISO	Independent System Operator
JPOI	Johannesburg Plan of Implementation
Kcmil	Thousands of circular mils (=0.0051cm2)
kJ	kilojoule; one thousand (10^3) Joules
kW	kilowatt; one thousand (10^3) Watts
kWh	kilowatt-hour; one thousand (10^3) Watt-hours

LOLP	Loss of load probability
LWR	Light-water reactor, the type of nuclear power generation reactor most common in most countries
MJ	Megajoule; one million (10^6) Joules
MOU	Memorandum of Understanding
MW	Megawatt; one million (10^6) Watts
MWh	Megawatt-hour; one million (10^6) Watt-hours
NEPAD	New Partnership for Africa’s Development
NERC	North American Electric Reliability Council
NO_x	Nitrogen oxides
NPP	Nuclear power plant
PTDF	Power transfer distribution factor
R	Resistance
RMS	Root mean square
SAPP	The Southern African Power Pool
SO_2 or SO_x	Sulfur dioxide or Sulfur oxides
TCE	Metric ton of coal equivalent, equal to 29.2 GJ
TOE:	Metric ton of oil equivalent, equal to 41.84 GJ
TSP	Total suspended particulates
TTC	Transmission transfer capacity
UNFCCC	United Nations Framework Convention on Climate Change
VAR	Volt-amperes reactive power
VOC	Volatile organic compound
V	Volt
VSC	Voltage source converter
VT	Voltage transformers
W	Watt
WB	The World Bank Group
WSSD	World Summit on Sustainable Development
Z	Impedance, the sum of resistance and reactance

EXECUTIVE SUMMARY

International electric grid interconnections are complex undertakings, with varied, varying, and potentially diverse issues, costs, and benefits. These issues, costs, and benefits are multi-disciplinary, almost always having technical, economic and financial, legal, political, social, and environmental aspects that must be considered.

Key **technical** aspects of grid interconnection include whether interconnected systems operate synchronously (at the same frequency) or asynchronously, what the magnitudes and directions of the anticipated power flows are to be, what physical distance and terrain will be spanned by the interconnection, and what the key technical and operating differences are among the systems to be interconnected. Key design and operating issues in alternating current (AC) interconnections relate to the constraints on transmission capacity (both of the interconnection and of the grids that it connects) which include thermal limits, stability limits, and voltage regulation. Where there are liberalized electricity markets, these constraints may become more severe as systems are operated closer to capacity in order to maximize net revenues. Simulation software is an essential tool for planning, assessing the technical benefits of, and operating an interconnection. For modeling to be effective, however, extensive technical data must first be gathered and shared between systems, and personnel must be trained. Grid interconnections require a careful calculation of costs, benefits, and risks. Technical planning of a grid interconnection should be coordinated with economic, organizational, legal, and political aspects of a potential interconnection project from the outset of project consideration.

Grid interconnections may offer both *direct* and *indirect* **economic and financial** costs and benefits. Examples of *direct* economic benefits to the electricity generation systems of one or all of the interconnected nations are "avoided costs" (direct costs avoided by the use of the interconnection) including costs for purchase and/or production of fuels used in electricity generation, capital costs of generation facilities, operating costs of generating facilities, and capital and operating costs for any transmission facilities avoided by the interconnection. Another direct economic and financial benefit of an interconnection to a country is income from power sales, with payments for power made in hard currencies of particular importance to many developing economies. Direct incurred costs related to the interconnection include the costs of fuels used to generate electricity for export (and of running the facilities needed to supply fuels), the capital and operating costs of generation facilities, and the costs of building and running the interconnection itself, as well as the costs of purchasing power.

The *indirect* costs and benefits of an interconnection potentially include the stimulation of national and local economies through employment of labor needed for facilities construction and, to a lesser extent, of the labor needed to operate the interconnection (and associated power plants) on an ongoing basis. Other potential indirect economic benefits of an interconnection include the impacts of improved power supplies on fostering development of local industry and improvements in education and health care, as well as the "re-spending" effect where electricity price reductions leave households with more disposable income available for other consumption, for savings, and for investment in productive activities. Depending on how the institution selling the power from the interconnection is configured, an interconnection may spur markets for power generation in one or more of the interconnected nations, further reducing electricity prices.

Pricing arrangements are needed to specify what the buyer(s) and seller(s) will pay and receive for electricity (electric energy and power) and electric system services (capacity and ancillary electric system services) provided through the interconnection. Prices can be specified based on production costs or avoided costs, or through negotiation, with market-based pricing a possibility where enough buyers and sellers exist to provide for structured, fair competition.

International electric grid interconnections, except perhaps in their very simplest forms, can be very complex **legal** undertakings, involving a variety of national, sub-national, and even international parties to the agreements required for planning, building, and operating power lines used to buy and sell electricity across borders. Binding legal agreements among countries and others involved in the project, as well as the negotiation processes that produce the agreements, must be transparent and enforceable. This requires national legal capacity to draft, review, enforce, adhere to and, in the event of a disagreement, adjudicate contract issues. Some of the key types of legal agreements needed to provide frameworks for international electric grid interconnections include power purchase and pricing agreements, agreements on siting of power lines and related infrastructure, agreements on power line operation (and operation authorities), agreements on power line security, agreements on the environmental performance of the interconnection, agreements on liability for power line failure, and agreements for the orderly, fair, and open selection of contractors to build and/or finance and/or operate and maintain interconnection infrastructure.

International electric grid interconnections may bring **political** benefits to the interconnected countries, including increased experience and political comfort with international cooperation, more reasons to avoid conflict with neighbors, increased democratization (depending, in part, on how the interconnection is designed and administered), and an increase in internal political stability. The existence of an interconnection, conversely, may be used as an excuse for internal political oppression, may give one of the interconnected countries more political and economic leverage over another, may entangle countries in each others' internal affairs, may provide potential for political graft, and may entail significant political costs for power line protection.

Political agreements both between and within countries are needed to underlie the types of legal agreements noted above. Political agreements are needed on sharing of power resources, moving forward with the interconnection project, how interconnection project contractors will be paid, and by whom, and how the benefits and costs of the project will be shared between and within nations. Agreements also are needed as to how the interconnection infrastructure will be operated and secured, including agreement on the governance of the interconnection operator, and how information necessary to plan, operate and protect the interconnection will be shared.

International grid interconnection projects may yield significant **social** *benefits*, as well as *costs*, to some or many groups in the nations participating in the projects. Potential *benefits* include better power quality, more reliable power, and more widespread availability of electricity to communities, income from power exports if spent toward social development goals, and the experience and incentive from interconnections for additional cooperative activities between countries. Potential social *costs* and/or liabilities of grid interconnection include potential physical separation of local groups from the resources that they use regularly, the importation of unwanted outside social influences to areas of infrastructure construction, the social impacts of export power plant construction, and the reduced incentive in power importing countries to use local resources, leading to increased vulnerability to supply disruptions.

International electric 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 locally, regionally, or globally significant air pollutant emissions, 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, through its impact on electricity generation and/or the use of other fuels in one or more of the nations participating in the project. 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 or impacts of one or several types in different locations, requiring a comprehensive evaluation to ensure that all environmental costs and benefits are taken into account.

Some of the key potential overall strategies for reaching the necessary agreements to implement an interconnection project include:

(a) Ensure the **fair distribution of economic, social, and other benefits and costs** among the nations involved in an interconnection, as well as among the groups within nations that are "stakeholders" in the interconnection;

(b) Ensure that the **direct costs and avoided costs of an interconnection are specified as accurately as possible**, preferably within the context of comprehensive long-term power system (and overall energy sector) planning. This includes assessments of **environmental** costs and benefits. Continue planning and assessment studies even after the project is implemented;

(c) **Emphasize transparency** in all negotiations related to grid interconnections, including allowing all stakeholders access to all relevant materials;

(d) Include **all** (or at least all major) **potentially affected parties in the early stages of project formulation**, and continue to solicit the input of all parties on key decisions throughout the project;

(e) Establish clear needs and protocols **for collecting and distributing quantitative data and other information** needed for project design, as well as for the accurate estimation of project costs and benefits;

(f) Establish **clear legal and administrative authorities** over all aspects of the design, construction, and operation of the grid interconnection;

(g) Work **with and through international and regional institutions**, including international financial institutions, to help smooth the path to political agreement, as well as to assist in providing the capacity for all groups to contribute meaningfully to decisions related to the interconnection;

(h) Locate new power lines in **existing transmission or transport corridors** as much as possible;

(i) Implement **capacity building** to allow different social stakeholder groups to meaningfully participate in investigating and deciding upon grid interconnection options and in planning for grid interconnection construction and operation.

Recommended areas of activity related to grid interconnections where United Nations agencies and other international organizations could usefully provide support and structure to assist in evaluating and, more importantly, developing the human capacity to evaluate international grid interconnection projects include:

(a) **Training** local and regional people in a number of both general and specific professional areas, ranging from electricity transmission engineering and power flow modeling to finance, utility management, law, marketing, regulation, negotiation and arbitration, information systems and database development, planning and policy development, data collection, and environmental analysis. Training should build as much as possible on existing centers of expertise within the region;

(b) **Compiling information** in a number of areas, including: technical parameters of power loads and flows in national transmission systems; the status of national and regional regulatory, financial, and legal systems; energy sector forecasts and planning results; demographic and social data; resource, hydrologic and environmental data; and data on the costs and performance of new energy and environmental technologies;

(c) **Sponsoring analytical activities** that is hard for individual countries or private groups to sponsor (or to sponsor in an inclusive manner), including power flow modeling of non-connected and interconnected systems, analysis of market systems for power trading, analyses of economic/environmental/social impacts (pre-, during, and post-project), and electric power sector and overall energy planning, including forecasts of demand for electricity and for energy services;

(d) **Providing support for engagement** by means of events and processes where counterparts from different regions and countries, and even sub-national stakeholders, can communicate, work, and learn together. Such opportunities include regional study groups on the technical, economic, legal/regulatory, political/social, and environmental aspects of interconnections to serve a particular area, national and regional stakeholder meetings regarding interconnection prospects in general and/or specific interconnection options in particular, and support (including capacity building, expertise, and project support) for the intervention of stakeholder groups in interconnection planning processes.

INTRODUCTION

A. GENERAL INTRODUCTION

International power grid interconnections provide links between the electricity transmission systems of two or more adjoining countries and thus allow those countries to share power generation resources. As different countries are differently endowed with natural resources, energy trade among countries for centuries (perhaps millennia) has helped to reduce energy prices and increase energy supply in importing countries, while providing a means of income for exporting countries. Most fuels can be transported by land or sea, by cart, freighter, truck, train, or tanker. Electricity, however, is generally not (yet) easily "storable" in bulk quantities and must therefore be transferred by power lines[1].

International grid interconnections can be as modest as the one-way transfer of a small amount of electricity from one country to another, or as ambitious as the full integration of the power systems and markets of all of the countries in a region. Whatever the scale, international power grid interconnections can help to contribute toward the process of sustainable development. Grid interconnections can help to increase the supply and/or reliability of electricity for use in education, employment generation, health care, and many other development related activities, and can contribute toward the formation of competitive markets for electricity on national and regional scales, helping to potentially reduce the cost of electricity to developing economies. International power grid interconnections are often, however, extremely complex undertakings, with technical, economic, legal, political, social, and environmental issues (costs, benefits, and considerations) that must be taken carefully into account before and as arrangements for power sharing are made.

A small sampling of the many issues associated with international power grid interconnections includes:

(a) **Technical** issues, such as grid stability benefits, potential costs in the form of impacts of technical problems in an interconnected network on the national grid, and considerations in transferring power between grids with different technical standards of power quality and reliability;

(b) **Economic** issues, such as benefits in the form of avoided fuel, capacity, and operating requirements for one or both countries (for example, through taking advantage of economies of scale), costs in the form of required payments for transmission infrastructure, and considerations such as deciding on electricity pricing, national contributions toward interconnection costs, and the impact of power from interconnections on local economies;

(c) **Legal** issues, including benefits in the form of model legal standards for cooperative activities of all types, costs such as the need to adapt national laws and practices to international standards, and complications such as determining jurisdictions for settling disputes, deciding on protocols for selecting contractors, and determining liability for third-party injuries due to activities related to the power line;

(d) **Political** issues, for example, benefits such as increasing cooperation and understanding between governments linked by the interconnections, liabilities such as additional exposure to potential political instabilities in a neighboring country, and considerations such as existing political rivalries between would-be electricity trading partners (or between sub-national groups within the trading nations);

(e) **Social** issues, with benefits in the form of improved access to electricity for development-related activities, but potential costs in the form of, for example, intrusion of power lines into traditional areas used by indigenous peoples, and considerations such as providing opportunities for all affected social groups to provide input into the interconnection planning process;

(f) **Environmental** issues, including potential benefits such as avoided greenhouse gas, regional, local, and indoor air pollution, possible costs such as the impacts of power lines on animal populations, and considerations such as compliance with local and international regulations and protocols, and coordination in operation of grid interconnections so as to maximize environmental benefits.

As such, any development of international electric grid interconnections requires thorough analysis that crosses a number of disciplines, from engineering and economics/finance to sociology and environmental science[2]. A thorough treatment of all of the issues noted above is well beyond the scope of this report. What this document seeks to provide, rather, is a survey of the costs, benefits, and other considerations that would require analysis in the evaluation and implementation of international grid interconnections, with some guidance as to tools and resources that can be used in grid interconnection planning.

B. BACKGROUND OF REPORT

1. Energy as an input to sustainable development

The improvement in the supply of energy services—the cooking of a meal, the cold-storage of food and medicines, the lighting of a room for reading, or the movement of goods or people from one place to another—is a crucial input to the development process. Electricity is arguably the most versatile form of energy, able to provide a wide variety of energy services, from running electronics, to providing light, motive power, and heat, typically as or more conveniently than other forms of energy, at high end-use efficiency, and with very low impacts on the environment and human health at the end-use level. The development (both in capacity and in stability) of a nation's electric power sector is thus to a large degree a prerequisite for growth in other sectors and for overall economic and social development. Unfortunately, a combination of factors ranging from small market size, inability to attract investments, poor management and maintenance of existing infrastructure, damages due to war and conflict, and inadequate and inappropriate tariffs and revenue collection often contribute to irregularities and shortages in electricity supply in developing regions, including many areas of Africa.

2. DESA's roles in promoting development in the energy sector

The United Nations Department of Economic and Social Affairs (DESA) has as one of its key goals the advancement of accessibility, availability, and acceptability of energy in all its forms to promote economic growth, environmental protection and social development. In developing countries, provision and consumption of energy and energy services will have to increase substantially to allow those countries to achieve development objectives and improve the quality of life of their citizens. The increased demand from developing countries will put upward pressure on the national and, ultimately, international supplies and prices of fuels, further compounding the challenge of delivering energy services to the poor, and further necessitating the need for multiple and complementary energy supply and distribution options.

Energy is one of the most internationally traded commodities. A dynamic perspective over time would reveal that this trade is continuously increasing both at the international level and at the regional level. The trade in energy is a positive factor in economic growth, and the international cooperation which supports it has become a major consideration in the evaluation of energy security issues today. International electric grid interconnections affect and are affected by a host of issues closely associated with energy security; supporting decision-makers in developing countries in carefully evaluating and addressing these issues is a key goal of DESA's activities and is the major focus of this report.

3. New Partnership for Africa's Development's objectives

An overview of the electric power sector in Africa reveals several common trends that are of relevance to an overall examination of trans-border electric grid interconnections:

(a) Varying degrees of privatization and restructuring of government-owned power companies have been undertaken by a number of countries, and are in varying stages of implementation;
(b) Shortages and irregularities in power supplies have forced many countries to look more closely at supplementing domestic supplies with trans-border networks and power pools; and
(c) Serious policy, investment, capacity and infrastructure challenges (including electricity theft, aging equipment, and infrastructure damage) continue to be associated with improving access to electricity in rural and peri-urban areas.

These difficulties are hardly unique to Africa, among developing (and re-industrializing) nations and regions, but they are perhaps more widespread in African countries than in any other region.

The Johannesburg Plan of Implementation (JPOI) of the World Summit on Sustainable Development (WSSD), recognizes that "access to energy facilitates the eradication of poverty" and underscores the critical linkages between meeting Africa's energy needs and achieving Africa's sustainable development objectives[3]. More specifically, the JPOI calls for supporting Africa's efforts to implement the New Partnership for Africa's Development's (NEPAD) objectives on energy which seek to secure access to "clean and affordable commercial energy supply" for at least 35 per cent of the African population within 20 years, especially in rural areas[4].

Noting that the development of cross-border energy trades is one of the goals for the energy sector of NEPAD, a recent DESA paper proposed the need for studies for electric power grid interconnections in Africa, and provided brief summaries of several ongoing interconnection projects in Africa that are in the planning and/or implementation phases[5]. To address this need, DESA has agreed with the "E7" group of major utilities and utility organizations from industrialized nations to initiate a series of seminars on grid interconnection seminars in selected African countries. These seminars will consist of the presentation of general guidelines and an overview of interconnection issues for certain regions in Africa.

4. Goal of the report

The purpose of this document, in keeping with DESA's support for sustainable development in Africa, is to provide input to the seminar series referenced above, but more generally to provide a review of the multi-disciplinary issues associated with grid interconnections worldwide. The overall goal of this report is to identify the issues associated with international electric grid interconnection so as to provide a resource for decision makers (and the engineers, economists, environmental and social scientists, and others who support them) in developing countries to analyze the roles that grid interconnections can play in the sustainable development of their countries and their regions, including the full costs, benefits, risks, and requirements of interconnection options. In so doing, the report is designed to help in the definition of a framework for cooperation between energy sector decision makers in countries considering grid interconnections.

C. EXISTING INTERCONNECTIONS AND INTERCONNECTIONS IN PROCESS

A number of interconnections in regions around the world are currently operating or in the planning phases, including[6]:

(a) **Europe's integrated markets**: Western and Central Europe, (UCTE); Scandinavia (NORD POOL); South-East Europe Regional Market; Baltic Electricity Market;
(b) **Commonwealth of Independent States** (CIS—the countries of the former Soviet Union) **countries**: increasing reintegration and trade;
(c) **North America**: The United States and Canada, with extensive electricity and gas trade;
(d) **South American electricity markets**: Southern Cone countries and the Andean Community of Nations;
(e) **Central America** (SIEPAC): efforts are under way to integrate electric systems;
(f) **Africa's integration efforts**: Southern Africa (The Southern African Power Pool, 1995); some interconnections and planned interconnections in the Nile River basin, West Africa, and East Africa;
(g) **Southeast Asia**: The Greater Mekong Subregion initiative for integrated electricity markets.

These and other interconnection efforts provide background and experience that can be drawn upon in the design of new interconnections. Virtually each new interconnection prospect, however, presents its own special set of multi-disciplinary issues that demand thorough and detailed consideration by a wide range of stakeholder groups.

D. ROAD MAP OF DOCUMENT

The remainder of this report is organized as follows:

(a) **Chapter I** provides a review of the **technical** aspects of grid interconnection, including the requirements and options for creating electric links between nations, and the types of information and modeling capacity needed to ensure that grid interconnections result in improved grid performance in all of the interconnected nations;
(b) **Chapter II** addresses the **economic and financial** aspects of grid integration, including noting the possible direct and indirect economic and financial costs and benefits of integration, as well as discussing some of the economic and financial arrangements needed between countries and with other participants in grid interconnection development;

(c) **Chapter III** reviews some of the **legal** aspects of grid interconnection, including a definition of the types of institutions that are often involved in legal agreements related to grid interconnections, and the types of agreement used, a review of the national attributes that help to ease the way for legal agreements, and potential benefits to national legal systems from experience with interconnection-related legal arrangements;

(d) **Chapter IV** identifies some of the **political** aspects of the integration of electric grids, including a review of the political characteristics of national political systems and international political relations that favor or make more difficult interconnection agreements, as well as a summary of some of the political benefits and liabilities that interconnection arrangements can bring with them;

(e) **Chapter V** describes some of the **social** aspects of grid interconnection, including the benefits of improved electricity supply and resource incomes for the interconnected societies, and the potential social liabilities of grid interconnection and the construction and operation infrastructure used to connect grids and produce electricity for trade;

(f) **Chapter VI** notes some of the **environmental** aspects of grid integration, including avoided air and water pollution from changes in the patterns of electric power generation and use of other forms of energy, the potential environmental and human health consequences of grid interconnections themselves, and the environmental impact assessment requirements that often accompany multilateral financing of international grid interconnections;

(g) **Chapter VII** summarizes the potential benefits and costs of grid integration with regard to **energy security** of the nations involved;

(h) **Chapter VIII** provides key conclusions from the materials presented in this report, and offers recommendations for follow-up activities associated with the analysis of the multi-disciplinary aspects of electric grid interconnections;

(i) A **Glossary** related to grid interconnections, as well as an **annotated bibliography** of additional reference materials, are included in this report.

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[1] Electric batteries, the most ubiquitous form of electricity storage available today, generally store electricity in small quantities and at high cost. The purchase of batteries for lanterns and entertainment devices can be a major expense for non-grid-connected households in developing areas.

[2] A set of documents that maps out a recommended approach to evaluating many, if not all, of the key aspects of electricity interconnections, as well as indicating some of the steps toward undertaking interconnections, is the compilation entitled Regional Electricity Cooperation and Integration (RECI): E7 Guidelines for the pooling of resources and the interconnection of electric power systems. This set of documents, consisting of a "Guidelines" overview, an Introduction, eight "Modules" and several attachments volumes, provides advice from the E7 Group of representatives of large utilities from the G7 group of industrialized nations. These documents are available from http://www.e7.org.

[3] The World Summit on Sustainable Development was held in Johannesburg, South Africa, from 26 August to 4 September 2002. The overriding theme of the Summit, as described in the Conference Press Release (http://www.un.org/events/wssd/pressreleases/finalrelease.pdf), "was to promote action and major progress was made in Johannesburg to address some of the most pressing concerns of poverty and the environment. Commitments were made to increase access to clean water and proper sanitation, to increase access to energy services, to improve health conditions and agriculture, particularly in drylands, and to better protect the world's biodiversity and ecosystems. The major outcome document, the Plan of Implementation, contains targets and timetables to spur action on a wide range of issues, including halving the proportion of people who lack access to clean water or proper sanitation by 2015, to restoring depleted fisheries to the preserving biodiversity by 2015, and phasing out of toxic chemicals by 2005. In addition, for the first time countries adopted commitments toward increasing the use of renewable energy 'with a sense of urgency,' Although a proposed target for this was not adopted. But rather than

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concluding with only the words of an agreed document, the Summit has also generated concrete partnership initiatives by and between governments, citizen groups and businesses. These partnerships are bringing with them additional resources and expertise to attain significant results where they matter—in communities across the globe." Additional reports from the Summit are available at http://www.un.org/jsummit/html/documents/summit_docs.html. The main Report of the Summit, including the Plan of Implementation, can be found at http://daccessdds.un.org/doc/UNDOC/GEN/N02/636/93/PDF/N0263693.pdf?OpenElement.

[4] The text of New Partnership for Africa's Development, from a conference held in Abuja, Nigeria in October, 2001, can be found at http://www.uneca.org/eca_resources/Conference_Reports_and_Other_Documents/nepad/NEPAD.htm.

[5] A. Cherian, "Development And Operation of Trans-Border Interconnections Of Electric Power Grids In Africa (An Overview)"., Paper prepared for DESA, and dated September 2003 [File name "Backup of African Grid Interconnection Sept 03.wbk"]. Another summary of many of the current and planned transmission interconnection projects in Africa is provided in section 6.2 of E.A.K. Kalitsi, "Problems And Prospects for Hydropower Development in Africa", presented at the Workshop for African Energy Experts on Operationalizing the NEPAD Energy Initiative, held 2 – 4 June 2003 in, Dakar, Senegal, and available as http://www.un.org/esa/sustdev/sdissues/energy/op/nepadkalitsi.pdf).

[6] Listing adapted from Vladislav Vucetic "South Asian Regional Energy Trade: Opportunities and Challenges", presented at The World Bank/International Monetary Fund Annual Meetings, held in Washington, D.C., 1 October 2004.. Available as http://siteresources.worldbank.org/INTSOUTHASIA/Resources/Energy_a.pdf.

I. TECHNICAL ASPECTS OF GRID INTERCONNECTION

A. INTRODUCTION

1. The evolution of interconnected systems

Electric grid interconnections have played a key role in the history of electric power systems. Most national and regional power systems that exist today began many decades ago as isolated systems, often as a single generator in a large city. As power systems expanded out from their urban cores, interconnections among neighboring systems became increasingly common[7]. Groups of utilities began to form power pools, allowing them to trade electricity and share capacity reserves. The first power pool in the United States was formed in the Connecticut Valley in 1925[8]. As transmission technologies improved, long distance interconnections developed, sometimes crossing national borders. The first international interconnections in Europe came in 1906, when Switzerland built transmission links to France and Italy.

One of the great engineering achievements of the last century has been the evolution of large synchronous alternating current (AC) power grids, in which all the interconnected systems maintain the same precise electrical frequency. Today, the North American power system is composed of four giant synchronous systems, namely the Eastern, Western, Texas, and Quebec interconnections. The Eastern interconnection by itself has been called the largest machine in the world, consisting of thousands of generators, millions of kilometers of transmission and distribution lines, and more than a billion different electrical loads. Despite this complexity, the network operates in synchronism as a single system. So does the Western European interconnection, which reaches from the UK and Scandinavia to Italy and Greece, embracing along the way much of Eastern Europe (for example, Poland, Hungary, Slovakia, and the Czech Republic). Synchronous interconnections among countries are expanding in Central and South America, North and Sub-Saharan Africa, and the Middle East[9].

At the same time that synchronous AC networks have reached the continental scale, the use of high voltage direct current (HVDC) interconnections is also rapidly expanding as a result of technical progress over the last two decades. HVDC permits the asynchronous interconnection of networks that operate at different frequencies or are otherwise incompatible, allowing them to exchange power without requiring the tight coordination of a synchronous network. HVDC has other advantages as well, especially for transmitting large amounts of power over very long distances. Fundamentals of both AC and DC interconnections are discussed below in Sections B, C, and D of this chapter.

2. General potential benefits of grid interconnections

There are number of technical rationales for grid interconnections, many of which have economic components as well (as described in Chapter II of this report). Technical rationales for grid interconnection include:

(a) Improving reliability and pooling reserves: The amount of reserve capacity that must be built by individual networks to ensure reliable operation when supplies are short can be reduced by sharing reserves within an interconnected network;

(b) Reduced investment in generating capacity: Individual systems can reduce their generating capacity requirement, or postpone the need to add new capacity, if they are able to share the generating resources of an interconnected system;

(c) Improving load factor and increasing load diversity: Systems operate most economically when the level of power demand is steady over time, as opposed to having high peaks. Poor load factors (the ratio of average to peak power demand) mean that utilities must construct generation capacity to meet peak requirements, but that this capacity sits idle much of the time. Systems can improve poor load factors by interconnecting to other systems with different types of loads, or loads with different daily or seasonal patterns that complement their own;

(d) Economies of scale in new construction: Unit costs of new generation and transmission capacity generally decline with increasing scale, up to a point. Sharing resources in an interconnected system can allow the construction of larger facilities with lower unit costs;

(e) Diversity of generation mix and supply security: Interconnections between systems that use different technologies and/or fuels to generate electricity provide greater security in the event that one kind of generation becomes limited (e.g., hydroelectricity in a year with little rainfall). Historically, this complementarity has been a strong incentive for interconnection between hydro-dominated systems and thermal-dominated systems. A larger and more diverse generation mix also implies more diversity in the types of forced outages that occur, improving reliability;

(f) Economic exchange: Interconnection allows the dispatch of the least costly generating units within the interconnected area, providing an overall cost savings that can be divided among the component systems. Alternatively, it allows inexpensive power from one system to be sold to systems with more expensive power;

(g) Environmental dispatch and new plant siting: Interconnections can allow generating units with lower environmental impacts to be used more, and units with higher impacts to be used less. In areas where environmental and land use constraints limit the siting of power plants, interconnections can allow new plant construction in less sensitive areas;

(h) Coordination of maintenance schedules: Interconnections permit planned outages of generating and transmission facilities for maintenance to be coordinated so that overall cost and reliability for the interconnected network is optimized.

Some costs and benefits of interconnections are difficult to quantify, but as a rough figure of merit it has been estimated that interconnections in North America have resulted in an overall annual cost savings of $20 billion in the 1990s, and that the Western European interconnection has resulted in reduced capacity requirements of 7-10 per cent.

3. Technical complexities and risks of grid interconnections

The fact that interconnections between power systems are increasingly common does not imply that they are as simple as connecting a few wires. Interconnections obviously entail the expense of constructing and operating transmission lines and substations, or in the case of HVDC, converter stations. Interconnections also entail other costs, technical complexities, and risks. For AC interconnections especially, a power system interconnection is a kind of marriage, because two systems become one in an important way when they operate in synchronism. To do this requires a high degree of technical compatibility and operational coordination, which grows in cost and complexity with the scale and inherent differences of the systems involved. To give just one example, when systems are interconnected, even if they are otherwise fully compatible, fault currents (the current that flows during a short circuit) generally increase, requiring the installation of higher capacity circuit breakers to maintain safety and reliability. Extensive planning studies, computer modeling, and exchange of data between the interconnected systems are needed to properly specify these and many other technical changes required by interconnection.

The difficulties of joint planning and operation of interconnected systems vary widely. As with marriages, from the institutional and administrative standpoint, coupled systems may become a single entity, or they may keep entirely separate accounts. Within the North American interconnections, for example, there are hundreds of electric utility companies that are entirely separate commercial entities. Customers receive power from, and pay bills to, the utility that serves their area, for example Consolidated Edison. They may do so without even knowing of the existence of the Eastern interconnection. Yet all the utilities in the Eastern interconnection are in a technical marriage that dictates or constrains key aspects of their technology choices and operating procedures.

Within countries, there are typically common technical standards for all utilities, which reduces the complexity of interconnecting separate systems. In different countries, on the other hand, power systems may have evolved quite separately, with very different standards and technologies, which adds an extra layer of technical complexity to interconnections. Institutional and administrative features of power systems in different countries are also likely to differ in many ways, and these differences invariably affect the technical and operational dimensions of an interconnection. Issues ranging from power trading agreements to reliability standards, although expressed in technical terms, often must be resolved within the realm of policy and political economy. As one expert on international interconnections has remarked, “many technical, organizational, commercial and political problems have had to be solved to get large networks linked by international interconnections to operate”[10].

The greatest benefits of interconnection are usually derived from synchronous AC operation, but this can also entail greater reliability risks. In any synchronous network, disturbances in one location are quickly felt in other locations. After interconnecting, a system that used to be isolated from disturbances in a neighboring system is now vulnerable to those disturbances. As major blackouts in North America and Europe in 2003 demonstrated, large-scale disturbances can propagate through interconnections and result in cascading outages, bringing down systems that had previously been functioning normally. In addition, long-distance interconnections with long transmission lines have potentially greater stability problems than is the case for shorter lines. Finally, many systems that have undergone electricity liberalization in recent years have experienced large increases in transmission capacity utilization, reducing reserve margins. Careful planning and well-coordinated operation are required to minimize the likelihood that an interconnection will lead to such problems as voltage collapse, dynamic and transient instability, or cascading outages due to propagated disturbances..

B. TECHNICAL PARAMETERS OF INTERCONNECTION

1. Basic electrical parameters

This section describes the basic electrical parameters and units of measurement used in electric power systems. It is meant to provide the non-technical reader with the concepts needed for a general understanding of the technical issues discussed in subsequent sections.

(a) AC & DC

Electric power comes in two forms: alternating current (AC) and direct current (DC). These forms are characterized by the behavior of their waveforms: AC alternates between positive and negative polarity with respect to ground, while DC does not. In power systems, AC is generally a sine wave, while DC is a constant value. Early electricity systems, such as Thomas Edison's Pearl Street Station in New York City, which provided the world's first public electric service in 1882, were DC. However, by the beginning of the 20th century AC systems had become standard worldwide. The main reason for the adoption of AC was that it is relatively simple to change AC voltage levels by using transformers, while it is difficult to change DC voltages. The development of solid-state power electronics in recent years has allowed an increased use of DC in the form of HVDC interconnections, but otherwise power systems remain AC.

(b) Frequency

Frequency is the rate at which an alternating current changes from positive to negative polarity, measured in cycles per second, or hertz (Hz). There are currently two widespread world standards for power system frequency: 50 Hz in most of Europe and Asia, and 60 Hz in North America and in other places strongly influenced by the U.S. power industry, such as South Korea. The choice of 50 or 60 Hz systems in different locations is a consequence of historical legacies rather than the inherent technical superiority of one or the other. However, the range of possible frequencies for power systems is constrained by practical concerns. For example, a century ago many electric railroads operated at a frequency of 25 Hz, but 25 Hz was never adopted for general use in power systems because frequencies at that level cause electric lights to flicker. At the other end of the scale, frequencies well above 60 Hz result in higher impedances, leading to unacceptably high transmission and distribution losses.

(c) Voltage

Voltage is the difference in electric potential between two points in an electric circuit. A difference in potential causes electric charges to flow from one place to another, just as a difference in heights causes water to flow from one level to another. Voltage is measured in volts (V), and sometimes in thousands of volts or kilovolts (kV).

In power systems, two important measures are the maximum voltage and average voltage at any particular point. Maximum voltage is important because insulation and safety equipment must be designed to protect against the highest voltage encountered. Average voltage is important because the amount of energy supplied to an end user or lost in transmission lines is a function of the average voltage and current. For DC systems, maximum and average voltages are the same, because DC voltage doesn't oscillate. For example, the output of a 120 V DC power supply is a continuous 120 V relative to ground, and this is both the maximum and average voltage.

For AC systems, different measures are required. In a 120 V AC system, the voltage actually oscillates in a sine wave between + 170 V and – 170 V relative to ground. The maximum voltage, also called amplitude or peak voltage, is thus 170 V. The simple arithmetic average of this waveform is actually 0 V, since the positive and negative voltages cancel each other out. Hence, another type of average is used, called root-mean-square (RMS). RMS is obtained by squaring the values of the voltage over one complete sine-wave cycle, determining its average value, and then taking the square root of that average. The result (true for any sine wave) is that $V_{RMS} = V_{PEAK} / \sqrt{2} = 0.707\ V_{PEAK}$. For a household system with a $V_{PEAK} = 170$ V, $V_{RMS} = 0.707\ (170\ V) = 120$ V. Thus the common designation of a household electric outlet as

"120 V AC" refers to the RMS value of the voltage. The voltages of power system components, such as transformers and transmission lines, are also generally given in RMS terms.

(d) Current

Current is the flow rate of electric charge. In an electric circuit, charge flows from a point of higher voltage to a point of lower voltage through a conductor, just as water flows from a higher spot to a lower one through a pipe. Current is measured in amperes (A) or kilo-amperes (kA), where one ampere is a certain number of charges (to be precise 6.25×10^{18} charges, called one coulomb) flowing per second. As is the case for voltage, AC currents are generally described in terms of their RMS values.

(e) Resistance and conductance

Conductance describes the ability of an object, such as an electric wire, to allow electric currents to flow. The reciprocal of conductance is resistance, which describes how much the object resists the flow of current. Resistance is measured in ohms (Ω). The resistance of wire is a product of its resistivity (an inherent property of the material from which it is made, such as copper or aluminum, for a given temperature) and the dimensions of the wire. For a given material, the longer the wire is, the greater the resistance, and the larger in diameter the wire is, the smaller the resistance. In the analogy of water flowing from a higher to a lower spot through a pipe, resistance is analogous to the friction of the pipe. A narrow pipe has a higher resistance; a wide pipe has a lower resistance.

(f) Ohm's Law

Ohm's Law describes the relationship among voltage (V), current (I), and resistance (R) across any element of a DC electric circuit as $V = I*R$. For a fixed value of resistance – say for an HVDC transmission line of a certain length and diameter – if the voltage is made larger, the current will decrease, and vice versa. For example, if the resistance of a line is 25 Ω, and the current through the line is 1 kA, then the voltage drop across the line is $V = 1 \text{ kA} * 25\ \Omega = 25$ kV. If the voltage on the sending side was 500 kV, then the voltage on the receiving side must be 25 kV less, or 475 kV.

(g) Power and energy

Power is the rate of energy flow, measured in watts (W), and sometimes in thousands of watts or kilowatts (kW), or in millions of watts or megawatts (MW). For a DC circuit, the power passing through any element of the circuit (e.g. a transmission line, a generator, an electrical appliance) is the product of the voltage across it and the current passing through it: $P = I*V$.

The energy delivered by a power system is measured in kilowatt-hours (kWh), and sometimes megawatt-hours (MWh). In general, energy is equal to power times time. For example, a light bulb that draws 100 W of power and is in use for 10 hours consumes a total amount of energy, E = 0.1 kW * 10 h = 1 kWh. Power and energy are quite different concepts. If an electric oven draws 1 kW of power and is in use for an hour, E = 1 kW * 1 h = 1 kWh. In these two examples, the power levels are different but the energy consumed is the same, the difference being the length of time that each device is operated.

The basic unit of energy is the joule (J), while the basic unit of power is the watt, where 1 W = 1 J/s. Thus 1 kWh = 1 kW * 1 h = 1000 J/s * 3600 s = 3.6 million J.

(h) Resistive losses

When current flows against a resistance, some of its energy is lost in the form of heating. For a DC circuit, the resistive losses can be calculated using Ohm's Law: $P_{LOSS} = I*V = I(I/R) = I^2R$. To continue with the example under "Ohm's Law" above, consider a 500 kV HVDC transmission line with 25 Ω of resistance, with 1 kA of current passing through it, and which has a voltage on the sending end of 500 kV, and a voltage on the receiving end of 475 kV. The total power being transmitted at the sending end of the transmission line is P = 500 kV ∗ 1 kA = 500 MW. Out of this 500 MW, the amount being lost to heating is $P_{LOSS} = (1\text{ kA})^2 * 25\ \Omega = 25$ MW. This constitutes 25 MW/500 MW or 5 per cent of the power being transmitted.

Very high voltages are used in transmission in order to reduce resistive losses to a tolerable level. In the example above, if the same amount of power were being transmitted (500 MW) but the sending voltage were 125 kV instead of 500 kV, the current through the line must be I = P/V = 500 MW/125 kV = 4 kA; the current is four times higher to yield the same amount of power, because the voltage is four times less. The power lost in the transmission line is then $P_{LOSS} = (4\text{ kA})^2 * 25\ \Omega = 400$ MW or 80 per cent of the power being transmitted. In general, line losses are inversely proportional to the square of the sending voltage; this is true for AC lines as well as DC. For this reason, managers of power systems historically have sought to increase transmission voltages as distances and amounts of power transmitted have grown. The highest common AC transmission voltages, sometimes referred to as extra high voltage (EHV), are 380 kV in Europe and 765 kV in the US. Voltages as high as 1200 kV have been used in Russia for some long-distance lines across Siberia. Above 1000 kV, however, the practical difficulty and expense of equipment and insulation that can withstand such high voltages becomes prohibitive.

(i) Impedance, reactance, inductance, capacitance

AC circuits involve not only resistance but other physical phenomena that impede the flow of current. These are inductance and capacitance, referred to collectively as *reactance*. When AC currents pass through a reactance (e.g. in transmission and distribution lines, in transformers, or in end-use equipment such as electric motors) some of the energy is temporarily stored in electro-magnetic fields. This has three important implications. First, even though energy is not "lost" to the environment as in the case of resistive heating, it must still be supplied to the reactive elements. This is known as reactive power. Second, voltage decreases when current flows across a reactance, just as it does across a resistance. For AC circuits, Ohm's Law must be modified: $\mathbb{V} = \mathbb{I}*\mathbb{Z}$, where $\mathbb{Z}$ is the sum of resistance and reactance, called *impedance*, and is measured in ohms. Third, $\mathbb{V}$, $\mathbb{I}$, and $\mathbb{Z}$ are all complex numbers, meaning that they express not only magnitudes in volts, amps, and ohms, but also phase angles. Voltage and current waveforms both oscillate at the same frequency - either 50 Hz or 60 Hz depending on the system – but they can differ in terms of the angular location within a cycle at which the maximum voltage or current occurs. This difference in angular location is referred to as phase difference, often symbolized by ϕ (phi) or θ (theta) and measured in degrees (or radians). Passing through an inductance causes an AC current waveform to fall behind, or *lag*, the voltage waveform. Passing through a capacitance causes AC current to move ahead of, or *lead*, the voltage. Equivalent amounts of capacitance and reactance cancel each other out.

(j) Complex power: real, reactive, apparent

For AC systems, there are three kinds of power: real, reactive, and apparent. Real power (sometimes called active power) is what is consumed by resistances, and is measured in W (or kW, or MW). Reactive power is consumed by reactances, and is measured in volt-amperes reactive, or VAR (sometimes kVAR, or MVAR). Apparent power is the complex sum of real and reactive power, and is measured in volt-amperes, or VA (or kVA or MVA). $S = \sqrt{(P^2 + Q^2)}$, where S is apparent power, P is real power, and Q is reactive power. Apparent power is what must be supplied by the generators in a power system to meet the system's electrical load, whereas end-use is generally measured in terms of real power only. Utilities always seek to minimize reactive power consumption, in part because it is difficult to measure and be compensated for reactive power by customers.

(k) Loads and power factors

An electrical load is the power drawn by an end-use device or customer connected to the power system. (Sometimes, "load" is used to refer to the end-use devices or customers themselves, but among engineers it usually refers to the power demand.) Loads can be resistive or reactive and are often a combination of both. The extent to which a load is resistive is measured by its *power factor* (p.f.), which is equal to the cosine of the phase difference between the current and voltage through the load (p.f. = $\cos \phi$). When the power factor is at its maximum value of one, the load is purely resistive. On the other hand, the smaller the power factor, the greater the phase difference and the greater the reactive power component of the load. Inductive loads, such as electric motors, have a *lagging* power factor and are said to *consume* reactive power. Capacitive loads have a *leading* power factor and are said to be sources of reactive power.

Given the voltages and currents through a circuit element, apparent, real, and reactive power can be calculated respectively as follows:

$S = I_{RMS} * V_{RMS}$

$P = S * \text{p.f.} = I_{RMS} * V_{RMS} * \cos \phi$

$Q = I_{RMS} * V_{RMS} * \sin \phi$

Reactive loads can have a large effect on line losses, because the current flowing through a line, and the associated heating, is a function of the apparent power S rather than the real power P. For example, consider a load of 150 kW with a lagging power factor of 0.75, which is supplied by a 10 kV distribution line with a resistance of 10 Ω. The apparent power drawn by the load is S = P/p.f. = 150 kW/0.75 = 200 kVA. The current to the load is then I = 200 kVA/10 kV = 20 A. The line loss is $P_{LOSS} = I^2 * R = (20\text{ A})^2 * 10\ \Omega = 4$ kW. If there were no reactive power consumption by the load, the power factor would be equal to one. In that case, S = P = 150 kW. Then I = 150 kW/10 kV = 15 A, and $P_{LOSS} = (15\text{ A})^2 * 10\ \Omega = 2.25$ kW. Thus the reactive load in this example increased the line losses from 2.25 kW to 4 kW, an increase of 78 per cent.

(l) Three-phase systems

House current is generally single-phase AC power, but the rest of the power system from generation to secondary distribution employs three-phase AC. This means that transmission lines have three separate conductors, each carrying one-third of the power. The waveforms of the voltage in each phase are separated by 120°. There are two major reasons that three-phase power became dominant. First, as long as the electrical loads on each phase are kept roughly balanced, only three wires are required to transmit power. Normally, any electric circuit requires both an "outbound" and "return" wire to make a complete circuit. Balanced three-phase circuits provide their own return, and thus only three, rather than six, wires are required to transmit the same amount of power as three comparable single-phase systems. Second, since the invention of polyphase induction motors by Nikola Tesla in the 1890s, three-phase motors have been the workhorse of industry. More than one phase is required to balance torque, which increases the effectiveness and lifetime of both motors and generators.

(m) Voltage and power in three-phase systems

The voltage in three-phase systems can be specified in two different ways. One is *phase to ground* which, as it sounds, is the voltage between any one of the three phases and ground. The other is *phase to phase*, which is the voltage between any two of the three phases. Power lines are conventionally described by their phase to phase voltage, also called the *line* voltage. Phase to phase voltage is greater than phase to ground voltage by a factor of the square root of three. Thus, a 500 kV line has a phase to phase voltage of 500 kV, and a phase to ground voltage of $500 \text{ kV}/\sqrt{3} = 289$ kV. In both cases, the voltage referred to is the RMS value.

The amount of power transmitted in a three-phase system is three times the power in each line. Thus $S = 3 (I * V_{LINE}/\sqrt{3}) = \sqrt{3}\, I * V_{LINE}$, where V_{LINE} is the phase to phase voltage. For example, the apparent power transmitted by a 500 kV circuit with a current of 1 kA is $S = \sqrt{3} * 500 \text{ kV} * 1 \text{ kA} = 866$ MVA. The real and reactive components can be calculated easily if the load power factor or phase difference is known. For example, if $\phi = 25°$, the real power $P = S \cos 25° = 866 \text{ MVA} * 0.906 = 785$ MW, and the reactive power $Q = S \sin 25° = 866 \text{ MVA} * 0.422 = 366$ MVAR.

2. Basic design features

The basic design features of an interconnection include the following elements:

- whether it is AC or DC
- if DC, whether it is single-pole or double-pole (+/-)
- transmission capacity (in MVA)
- transmission voltage (in kV)
- system components and overall design
- operating agreement

These features are dictated by the answers to the following questions:

(a) Will the interconnected systems operate synchronously or asynchronously? To operate synchronously, at a minimum the systems must have the same nominal frequency (50 Hz or 60 Hz). Even if frequencies are the same, technical and operational differences can make synchronous operation too difficult or expensive to pursue. Many synchronous networks with the same nominal frequency, including the four North American interconnections, have only asynchronous DC connections between them;

(b) What are the magnitudes and directions of the anticipated power flows? The basic rationales for the interconnection must be expressed quantitatively, using models that forecast the power flows through the interconnection among constituent systems. The forecasts must be conducted on different time scales: diurnal, seasonal, annual, and multi-year projections;

(c) What physical distance and terrain will the interconnection span? The peak power flows and the physical length of the interconnection will influence the choice of AC or DC, the size of conductors, and requirements for other system components, such as series capacitors or phase-shifting transformers. Terrain, geology, and land use considerations (such as urban areas, environmentally sensitive areas) will determine the type of lines or cables used (overhead or underground) , the layout and design of substations or converter stations, grounding and lightning protection schemes, and the most suitable kinds of support structures. Undersea transmission requires the use of special cables that are quite different from terrestrial cables and overhead lines. Terrain and land use also dictate construction and maintenance methods;

(d) What are the key technical and operating differences among the systems to be interconnected? These include differences in the hardware, control systems, and procedures used for frequency regulation, voltage regulation, and fault protection.

3. Interconnection elements

A listing of the basic elements of an interconnection is provided below.

(a) Technical objectives

The ultimate objective of an interconnection, like the power systems it is part of, is to provide power to customers economically, safely, reliably, efficiently, and with minimal environmental impact. Each of these aspects has one or more quantitative measure, such as price per kilowatt-hour, number and lethality of accidents, frequency and duration of service interruptions, generating plant heat rate, transmission and distribution losses, and emissions factors. Interconnections are designed, and their individual components selected, with all of these objectives in mind, though they may be optimized differently in different systems.

(b) Transmission lines

Transmission lines come in two basic varieties: overhead lines and underground (or undersea) cables. Overhead lines are more common and generally less expensive than cables. The main design consideration for overhead lines is the choice of conductor type and size, which must balance the need to minimize impedance (and the associated losses), minimize cost, and minimize the weight that must be carried by support structures. Although copper is a better conductor, it has been overtaken in recent years by aluminum, which is lighter, cheaper, and in abundant supply. The most common variety of overhead conductor for high-capacity, long-distance transmission is stranded aluminum wire reinforced with steel (known as ACSR, for “aluminum conductor steel reinforced”). Other design considerations for overhead lines are the type of support structures (such as transmission towers and insulators) used, and the configuration of conductors on the support structures, which affects the reactance of the conductors and the strength of electromagnetic fields (EMFs) around the lines.

Underground cables are used where overhead conductors are inappropriate due to environmental or land use considerations, such as in high-density urban areas or ecologically sensitive areas. Cables are insulated, are typically routed through underground conduits, and often require cooling systems to dissipate heat. Cables may use copper instead of aluminum, balancing the greater cost of copper against its superior conductivity and lower resistive heating. Undersea cables are usually made of copper, and may be surrounded by oil or an oil-soaked medium, then encased in insulating material to protect from corrosion. Undersea cables often have a coaxial structure, which has an inherently high capacitive reactance; therefore, undersea cables are usually DC, which is not affected by reactance. Conductor cross-sections are typically measured in square centimeters (cm^2) in the metric system, or thousands of circular mils (kcmil) in the American system[11]. The capacity of a conductor to carry current without exceeding thermal limits is called its ampacity, measured in kA for large conductors.

(c) Support Structures

There are many possible types of support structures for overhead transmission lines. In developed countries, transmission lines are supported on structures made out of steel lattice, tubular steel, wood, and concrete. Of these, steel lattice has the highest strength to weight ratio and is the easiest to assemble in areas that are difficult to access[12]. Where aesthetics are an important factor, however, other materials are often used. The main function of support structures is to keep the conductors from contacting trees or other objects, including people and animals; thus, the structures must be tall enough to do so even when the conductors sag due to high temperatures caused by resistive heating. All things being equal, taller structures also minimize ground-level EMFs. Because overhead transmission lines are not insulated, they are typically suspended from towers on strings of ceramic insulators, which are designed to prevent flashover, or the leakage of current from the conductors to the tower, which would present a lethal prospect to anyone touching the tower. AC transmission towers are usually designed to carry three conductors: the three phases of AC power systems. Towers that hold these in an equilateral triangle shape (called a “delta”) keep the mutual reactances of the three phases balanced; non-delta configurations often require that conductors be *transposed*, or switch places, at regular intervals along the transmission path. Some towers carry more than one circuit, with three phases per circuit; for example, a double-circuit tower will have six conductors. (The conductor for each phase may also be subdivided into “bundles” of two or more conductors, which are physically close together.) DC transmission towers carry two conductors per circuit. Figure I.1 shows various options for transmission tower design.

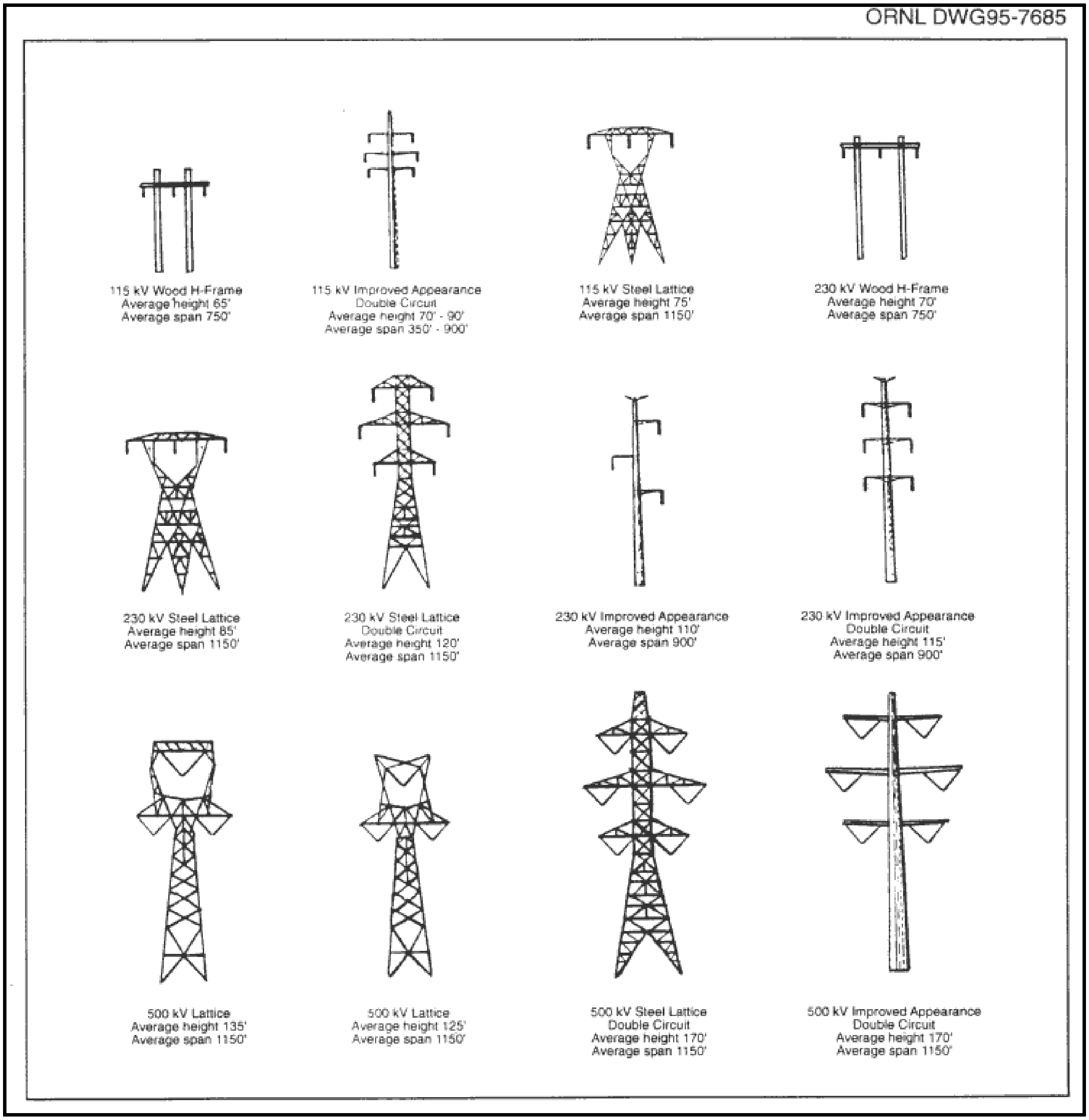


Figure I.1. Common configurations for transmission towers.

(d) Transformers and substations

Transformers are used to change voltage levels in AC circuits, allowing transmission at high voltages to minimize resistive losses and distribution to the consumer at low voltages to maximize safety. This ability, following the development of transformers by William Stanley in 1885, led to the rapid adoption of AC systems over DC systems. The essential element of a transformer consists of two coils of wire wrapped around an iron core. An alternating current in one coil produces a changing electromagnetic field that induces a current in the other. The voltages on either side are in the same ratio as the number of turns on each coil. For example, a transformer that has a 10:1 “turns ratio” and is connected to a 15 kV supply on its *primary* side will have a voltage of 150 kV on its *secondary* side. Transformers step up the voltage from generator to transmission system, and other transformers step it down, often in several stages, from transmission to sub-transmission to primary distribution to secondary distribution, and finally to the end-user voltage, such as 120 V. At the distribution level, transformers often have *taps* that can be used to change the turns ratio; this allows operators to maintain customer voltage levels when system voltages change. Modern transformers are typically more than 99% efficient, but even small losses can produce a great deal of heat, which must be dissipated to prevent damage to the equipment. Large transformers are cooled by circulating oil, which also functions as an electrical insulator.

Large transformers are housed in substations, where sections of a transmission and distribution system operating at different voltages are joined. Larger substations have a manned control room, while smaller substations often operate automatically. In addition to transformers, important substation equipment includes switchgear, circuit breakers and other protective equipment (see next section), and capacitor banks used to provide reactive power support.

(e) Protection systems

Protection systems are an extremely important part of any power system. Their primary function is to detect and clear *faults*, which are inadvertent electrical connections – that is, short circuits – between system components at different voltages. When faults occur, very high currents can result, typically 2-10 times as high as normal load currents. Since power is proportional to I^2, a great deal of energy can be delivered to unintended recipients in a very short time. The goal of protection systems is to isolate and de-energize faults before they can harm personnel or cause serious damage to equipment. Protection systems are designed to protect the power system itself, rather than end-user equipment.

The key components of protection systems are circuit breakers, instrument transformers, and relays. Circuit breakers are designed to interrupt a circuit in which high levels of current are flowing, typically within three voltage cycles (about 50 milliseconds in a 60 Hz system). To do this they must quench the electric arc that appears when the breaker contacts are opened; this is usually accomplished by blowing a gas, such as compressed air or sulfur hexafluoride (SF_6) across the contacts. Since human operators generally could not respond to a fault in time to prevent damage, circuit breakers are operated by automatic relays that sense faults or other undesirable system conditions. To distinguish between normal operations and fault conditions, relays are connected to instrument transformers – voltage transformers (VT) and current transformers (CT) – that reflect the voltages and currents of the equipment to which they are connected. Relays themselves can be either electromechanical or solid state devices.

Essential aspects of protection system design include determining the specifications and placement of protection equipment, and also determining the correct timing and sequence of relay operations. Protection engineers must determine how long an undesirable condition should be allowed to persist before opening a circuit breaker, and the order in which circuit breakers must be opened to correctly isolate faults in different zones[13].

(f) Communications, monitoring, and control systems

Power system operations take place within geographically well-defined *control areas*, which traditionally corresponded to a utility's service territory. With market liberalization, individual utility control areas have sometimes been combined into larger control areas under the jurisdiction of an independent system operator (ISO). In either case, system operations are coordinated by a central control center, the responsibility of which it is to keep the entire system running safely and reliably. This entails continuously monitoring system conditions and deploying system resources as the situation requires.

Traditionally, monitoring and control have been conducted semi-manually, with a heavy reliance on telephone communications with plant operators and field personnel. Increasingly, these activities are automated. Supervisory control and data acquisition (SCADA) systems combine remote sensing of system conditions with remote control over operations. For example, control center SCADA systems control key generators through automatic generator control (AGC), and can change the topology of the transmission and distribution network by remotely opening or closing circuit breakers. This monitoring and control is enabled by dedicated phone systems (often fiber-optic based), microwave radio, and/or power line carrier signals.

C. TECHNICAL ISSUES ASSOCIATED WITH AC GRID INTERCONNECTION

1. General requirements for AC interconnection

AC interconnection usually provides the greatest interconnection benefits, except in certain cases for which DC is the preferred option (see Section D.1). Synchronous interconnection of different systems is, however, technically demanding. At a general level, the first requirement is that the systems share the same nominal frequency, either 50 Hz or 60 Hz. Then, they must regulate frequency so that they achieve and remain in synchronism (see Section C.4, below). They must also interconnect at a common voltage level. This is easier if the countries involved have agreed to a common standard for transmission voltage, such as the 380 kV standard in Europe. It is still possible for countries with different voltage schemes to interconnect by using transformers (if voltages are not very different, *autotransformers* are often used, which have only a single winding and are less expensive than ordinary transformers). Having to use an excessive number of transformers is, however, undesirable, as transformers are costly, add impedance to the line, and may require lengthy repair after a fault, keeping the transmission intertie out of operation for an extended period[14]. Other, more specific technical issues are discussed in the remainder of this section.

Good engineering must be complemented by good cooperation among the interconnected systems. In both planning and operation phases, this requires extensive data sharing, joint modeling, and clear communication.

2. Technical issues for AC interconnection

One way of thinking about the technical issues of AC interconnections is to group them into those associated with the transmission interconnection itself, and those associated with operating the larger interconnected system. Transmission issues are discussed in C.3. Key issues include thermal limits, stability limits, and voltage regulation, which are the main constraints on transmission line operation. Other transmission issues include loop and parallel path flows, available transfer capacity, and FACTS technologies. System-wide issues are discussed in C.4, including frequency regulation, power quality, the coordination of planning and operations, political and institutional cooperation, systems that are aging or in poor repair, and the operation of nuclear power plants. The implications of electricity market liberalization for interconnected systems are also discussed.

3. Transmission issues

(a) <u>Thermal limits</u>

The capacity of transmission lines, transformers, and other equipment is determined by temperature limits. If these limits are exceeded, the equipment can be damaged or destroyed.

Equipment ratings have traditionally been conservative and operators have stayed well below the rated limits, but increased power trading in liberalized markets has created pressure for higher utilization. Instead of a single thermal limit, dynamic ratings are now often used. For example, transmission lines can carry more current when heat is effectively dissipated and thus will have a higher rating on cold, windy days without direct sunlight.

When transmission lines heat up, the metal expands and the line sags. If the sag becomes too great, lines can come into contact with surrounding objects, causing a fault. Excess sag can also cause the metal to lose tensile strength due to annealing, after which it will not shrink back to its original length. Important transmission lines are often monitored by a device called a "sagometer", which measures the amount of sag, making system operators aware of dangerous sag conditions.

(b) Stability limits

The stability limit of a transmission line is the maximum amount of power that can be transmitted for which the system will remain synchronized if a disturbance occurs. The power flow through a transmission line is governed by the difference in power angle between the sending and receiving sides:

$$P = V_R * V_S * \sin\delta \; / \; X$$

All other factors being equal, the power transmitted from the sending side to the receiving side increases as the difference in power angle between the two points, called δ (delta), approaches 90°, and decreases as it approaches 0°. However, the feedback mechanism that keeps generators in synchronism and returns them to synchronous operation if they are disturbed becomes more tenuous as δ approaches 90°. The stability limit represents the value of the power angle that allows the highest power transfer while maintaining stability; a typical maximum value of δ is around 45°.

In general, stability limits are more important than thermal limits for long transmission lines, while thermal limits are more important for shorter lines. In the United States, for example, thermal limits are more important in the Eastern interconnection, while stability limits play a larger role in the Western interconnection.

(c) Voltage regulation

Utilities generally maintain system voltages within 5-10 per cent of nominal values in order to avoid the risk of voltage collapse, which can lead to a major interruption of service. Power system voltages are primarily governed by reactive power flows. Voltages along a transmission link are a function of the physical length of the circuit, the impedance per unit length, and the flow of real power: the higher the current and the greater the reactance, the larger the voltage drop (if the reactance is predominantly inductive) or gain (if capacitive). Voltage collapse can be triggered when reactive demand is high and systems operate near their stability limits and then undergo a disturbance that triggers a quick downward spiral. To maintain voltages along long AC transmission lines, reactive compensation of various kinds can be employed, such as series and shunt capacitors, and shunt reactors. (See section on FACTS, below.)

System operators also maintain voltage levels in order to protect end-use equipment (for example, low voltages cause motor currents to increase, and higher currents can cause thermal damage). Utilities are usually obliged to provide power to customers within prescribed voltage tolerances. Devices called tap-changing transformers in the local distribution system are used to ensure that customer voltages are maintained even when system voltages change substantially.

The power quality experienced by the customer, however, is generally more affected by local conditions in the distribution system, such as switching, lightning strikes, and the loads of other customers, than by conditions in the transmission system. Protecting sensitive electronic end-use equipment is the responsibility of the customer rather than the utility.

(d) Loop and parallel path flows

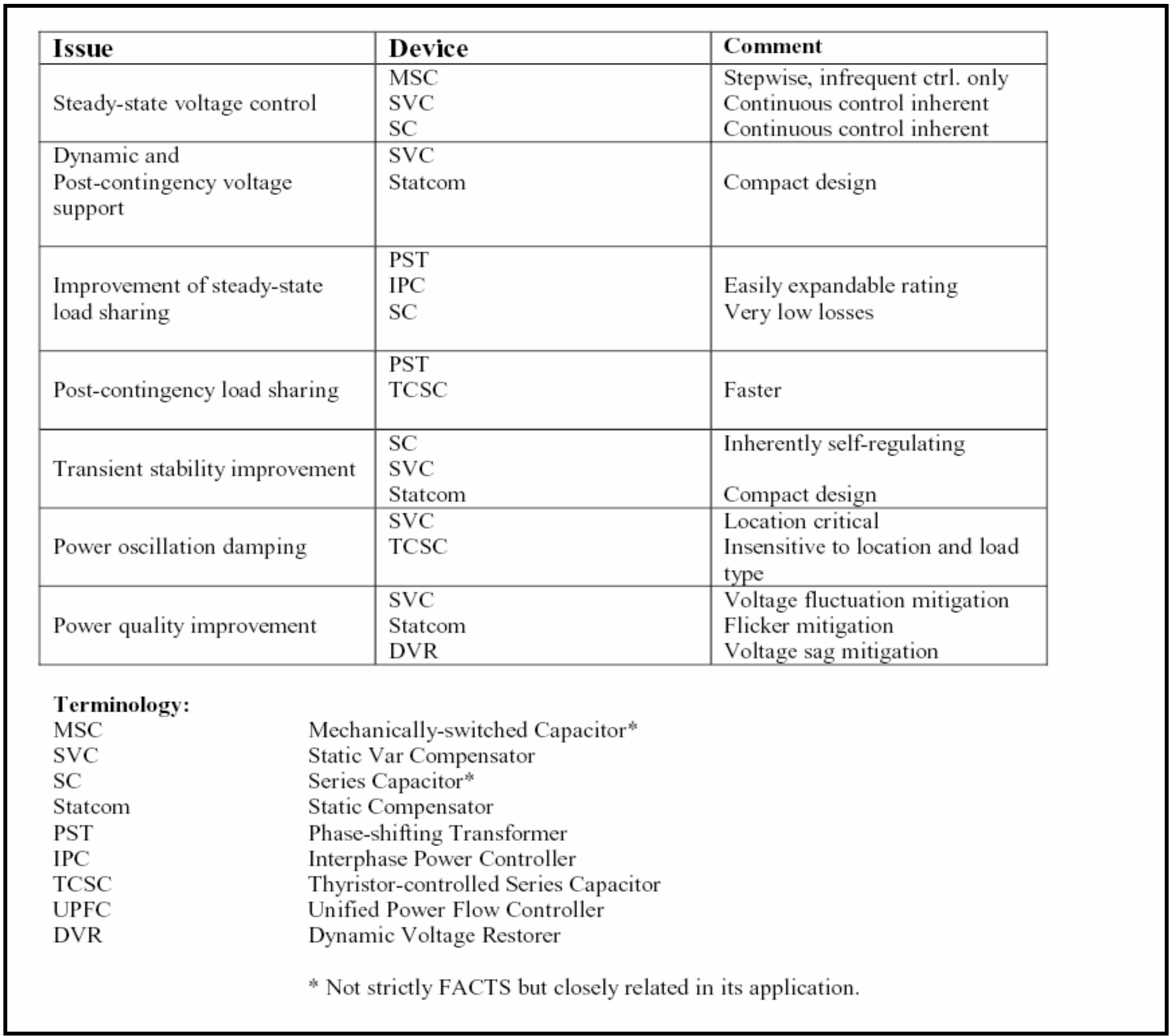
In power systems, power flows do not necessarily follow a specified transmission path (for example, from seller in system A to buyer in system B) but divide themselves among various connected transmission paths according to the voltage levels and impedances of the path. To put it another way, power flows conform to physical laws rather than economic agreements. In some cases, a power transaction can take quite unwanted paths, resulting in line losses and possibly overloading lines of neighbors having nothing to do economically with the transaction. In general, these phenomena are referred to as circulating power, loop flows, and parallel path flows. A well-known example of these flows is that in a power transfer from the U.S. Pacific Northwest to the state of Utah, one-third of the power flows through Southern California, and another one-third flows through Arizona.[15] What is important for the reliability of an interconnected system is that operators know the sources and destinations of all transactions and where the power will flow, and are able to calculate the resulting reliability risks (see Section E.2 below).

(e) Available transmission capacity (ATC)

An important measure of transmission capacity is transmission transfer capability (TTC), which is the maximum power flow that a line can accommodate at any given time and still be able to survive the loss of a major generator or transmission link elsewhere in the system. Available transmission capacity (ATC) is the TTC of a line minus the amount of capacity already committed to other uses on that line. ATC is thus the measure of how much power can be safely transmitted over a transmission line at a given time while ensuring overall system reliability.

(f) Flexible AC Transmission System (FACTS)

Flexible AC Transmission System (FACTS) refers to a number of different technologies based on power electronics and advanced control technologies, which are used to optimize power flows and increase grid stability[16]. FACTS equipment is expensive, but it can pay for itself by directing power flows with precision, eliminating loop flows, and relieving transmission bottlenecks without requiring that new lines be built. It can also improve frequency and voltage stability, decrease transmission losses and voltage drops, and improve power quality. FACTS equipment includes static compensators, static VAR compensators, thyristor-controlled series capacitors, phase-shifting transformers, interphase power controllers, universal power flow controllers, and dynamic voltage restorers. With FACTS, AC transmission has become possible over distances that were not previously possible due to stability limits. Figure I.2 shows applications for different FACTS technologies. FACTS devices have been used extensively in the North American and European interconnections, and increasingly in developing regions, including the South Africa-Zimbabwe interconnection, the Brazil north-south interconnection, and other interconnections in Latin America, Africa, and South Asia.



Issue	Device	Comment
Steady-state voltage control	MSC SVC SC	Stepwise, infrequent ctrl. only Continuous control inherent Continuous control inherent
Dynamic and Post-contingency voltage support	SVC Statcom	Compact design
Improvement of steady-state load sharing	PST IPC SC	Easily expandable rating Very low losses
Post-contingency load sharing	PST TCSC	Faster
Transient stability improvement	SC SVC Statcom	Inherently self-regulating Compact design
Power oscillation damping	SVC TCSC	Location critical Insensitive to location and load type
Power quality improvement	SVC Statcom DVR	Voltage fluctuation mitigation Flicker mitigation Voltage sag mitigation

Terminology:

MSC	Mechanically-switched Capacitor*
SVC	Static Var Compensator
SC	Series Capacitor*
Statcom	Static Compensator
PST	Phase-shifting Transformer
IPC	Interphase Power Controller
TCSC	Thyristor-controlled Series Capacitor
UPFC	Unified Power Flow Controller
DVR	Dynamic Voltage Restorer

* Not strictly FACTS but closely related in its application.

Figure I.2: Applications of FACTS technologies[17]

(g) Transmission upgrades

If existing transmission facilities are to be used in the interconnection but are not adequate to transmit the expected volume of power, they can be upgraded either by adding additional lines in parallel or increasing the transmission voltage. If these options are not available, FACTS or HVDC solutions can be explored.

4. Systems issues

Key technical systems issues that must be addressed in planning and implementing a grid interconnection include frequency regulation, coordination of operations, interconnections of power systems with weak grids, and aspects of interconnection that are associated with electricity market liberalization.

(a) Frequency regulation

Controlling frequency in a synchronous network is ultimately an issue of precisely matching generation to load. This load-matching occurs on several time scales. System planners and operators plan generation from hours to months in advance, coordinating the dispatch of generating units and power exchanges with other systems based on factors such as historical load patterns, weather predictions, maintenance schedules, and unplanned outages. At the scale of minutes to seconds, frequency is maintained by Automatic Generator Control (AGC), which precisely controls the real and reactive power output of certain generators that are able to respond rapidly to changes in load. Hydroelectric and gas turbine units are generally used for regulation and load following; nuclear plants and large coal-fired plants can be damaged by rapid changes of output and are not used in this function.

At the instantaneous time scale, frequency synchronization is a self-regulating phenomenon. When loads suddenly increase, generators slow down slightly, giving up some of their mechanical energy of rotation to supply the additional electric energy required; when loads suddenly decrease, generators speed up. Through feedback among the different generators in the system, synchronism is maintained, at a frequency slightly higher or lower than nominal. When the control center computers sense these frequency movements, AGCs are notified to increase or decrease generator output to the amount necessary to balance load and return frequency to nominal levels. System operators also have a variety of off-line reserves or "ancillary services" available upon need to assist in frequency regulation and other aspects of reliable system operation. Once a daunting engineering problem, the theory of parallel operation of generators in large networks was established in the 1930s. Modern networks seldom deviate from nominal frequency by more than 0.1 Hz, and generally operate within 0.01 Hz of nominal.

In an interconnected system, except where DC links are used, frequency synchronization must be accomplished through the means above, jointly administered across the interconnected systems.

(b) Coordinating operations

The basic geographical unit of a power system is the control area, which typically has a single control center responsible for monitoring system conditions and scheduling the dispatch of all generation. In interconnected systems, transmission lines to neighboring control areas are metered and the incoming and outgoing power flows are scheduled and continuously monitored. The Area Control Error (ACE), a continuous record of the balance of load, generation, and exchanges with other control areas, is used to plan real-time corrections to maintain load-generation balance.

Interconnections create a number of coordination challenges, both institutional and technical. For example, reliability standards and constraints may differ, and there may be differences in regulation and control schemes and technologies. It is important for the operators and planners of interconnected systems to be aware of the conditions and practices in their neighboring control areas. Good communication between different system operators is important for agreeing on and coordinating interchange schedules, transmission loading, maintenance schedules, procedures for fault clearing, and emergency protocols[18].

As interconnected systems expand to encompass large geographical scales, technology is striving to keep up with the associated complexities and risks. Some important trends in grid technologies related to the problems of maintaining reliability in large AC systems include[19]:

(1) Faster physical control over the system, for example FACTS technologies with solid state controls that allow rapid adjustment of reactive power flows;
(2) Improved real-time monitoring ability, for example the development of wide area monitoring systems (WAMS);
(3) Faster analytical capability to complement improved monitoring;
(4) Improved communications.

(c) Interconnection of power systems with weak grids

Not all interconnections take place between power systems in top technical condition. In the developing world, many power systems bear the marks of age, poor repair, and insufficient investment, ranging from corroded conductors and deteriorating insulation to leaking transformers, worn out switchgear, and a variety of inoperable equipment. Equipment is often obsolete, and operations that are automated elsewhere may be carried out manually. Systems in poor repair generally perform poorly, have serious reliability problems, and often fail to comply with safety or environmental standards. As one scholar described the difficulties of interconnection among sparse, poorly maintained systems:

> "The vastness of the area and the low power consumption density in most African countries makes the operation of the interconnection difficult from an operational point. Many of the loads are connected to spurs off a grid that has a low level of interconnectivity. In addition, most of the networks have suffered from a lack of maintenance due to a shortage of funds. This has dramatically reduced the reliability of the system and outages frequently occur in many places....The combination of these factors has forced industries to provide their own generating facilities in the form of diesel power. These plants then operate in island mode and will often also provide power to towns and villages in the immediate vicinity of the plant....Some utilities are discouraging this practice, but need to convince these clients to connect to a grid that may not be that reliable in the first place, particularly in areas connected to spurs."[20]

Interconnection can improve such systems, by providing emergency reserves and more reliable supplies. However, careful planning must ensure that the interconnection doesn't lead to additional stresses elsewhere in the interconnected system.

Countries with weak or isolated grids are usually poor candidates for siting nuclear power plants (NPP). NPPs have much more stringent requirements regarding grid stability than do fossil fuel thermal plants, for two reasons. First, the auxiliary systems in a NPP are much more sensitive to power conditions than such systems at other plants because of the potential consequences – namely, that a major failure could lead to a nuclear accident. Second, NPPs have large amounts of decay heat to remove long after the chain reaction is shut down, and require power to operate cooling water pumps during this extended period. With weak grids, large variations in voltage and frequency will trip a NPP off-line; worse, the sudden loss of a large power plant starts a cascading failure that collapses the grid altogether. With interconnection to other grids, however, siting a NPP in a country with a weak or isolated grid becomes a plausible option. The interconnection can help to stabilize the weak grid, and it can also provide access to an independent back-up grid connection, which is a safety requirement for NPPs[21].

(d) Interconnections and electricity market liberalization

Electricity market liberalization presents a combination of opportunities, challenges, and risks for interconnection projects. From the economic standpoint, the opportunity of greater access to lower-cost supplies is balanced against the challenge of operating competitive markets and the risk of market breakdowns of the type that occurred in California in 2000-2001. From the technical standpoint, the focus is on the impact of liberalization on reliability[22]. Some of the main concerns that have been raised include:

- Increased or excessive utilization of transmission capacity, reducing reliability margins

- Reduced information exchange among system operators due to proprietary concerns in a competitive environment
- Reduced investment in reliability as companies cut costs due to competitive pressures, a concern for transmission especially as generation and distribution are liberalized
- Increased complexity in planning and operations as the number of players and transactions increases, and dispatch is based on changing market prices
- The intentional creation of congestion, or the appearance of congestion, on transmission lines to drive up prices, as done by Enron and others during the California crisis
- Transaction costs associated with replacing experienced organizations and procedures with new ones as ISOs and TRANSCOs replace integrated utility control areas.

Requirements for successful interconnection operation in a liberalized, more market-driven electricity sector environment include[23]:

- Making knowledge of all transactions available to system operators
- Improving cooperation between network managers of different countries
- Improving incentives for investing in infrastructure
- Clearly defining the rights and obligations of all parties
- Monitoring behavior and rigorously enforce rules.

D. TECHNICAL ISSUES RELATED TO DC INTERCONNECTIONS[24]

1. Why use HVDC?

The first electrical transmission systems built in the 1880s were DC. However, because DC could not be readily transformed to higher voltages for long distance transmission, AC systems quickly became the standard. It was many years before technological development again made DC competitive for some applications. The first commercial use of modern HVDC transmission was in Sweden in 1954. Since the 1980s, when high-voltage solid state converters were developed to replace mercury arc converters, the use of HVDC transmission in interconnection projects has taken off. While still expensive, costs of converter stations have been steadily falling, and HVDC must be considered as an option for many interconnection projects.

HVDC is used in interconnection projects in three principal applications discussed below.

(a) <u>Transmitting large amounts of power over very long distances</u>

Unlike long-distance AC transmission, HVDC transmission over long distances has no inherent stability limit. Also, even within AC stability limits (which can be extended through the use of FACTS or other reactive compensation), HVDC can overtake AC on cost grounds alone. This is because HVDC carries more power for a given conductor size and only requires two conductors while AC transmission requires three. Thus, even though converter stations are very expensive, the cost per kilometer of DC transmission lines is lower. Generally, for distances above about 600 km, HVDC transmission is less expensive to build and operate than AC. The relationship between costs of AC and DC transmission lines versus the distance that power must be transmitted is illustrated in Figure I.3. The dashed lines in this figure illustrate only terminal (converter station for DC, substation for AC) and line costs; the solid lines show that HVDC economics are improved when consideration of the relative line losses of the two technologies are included.

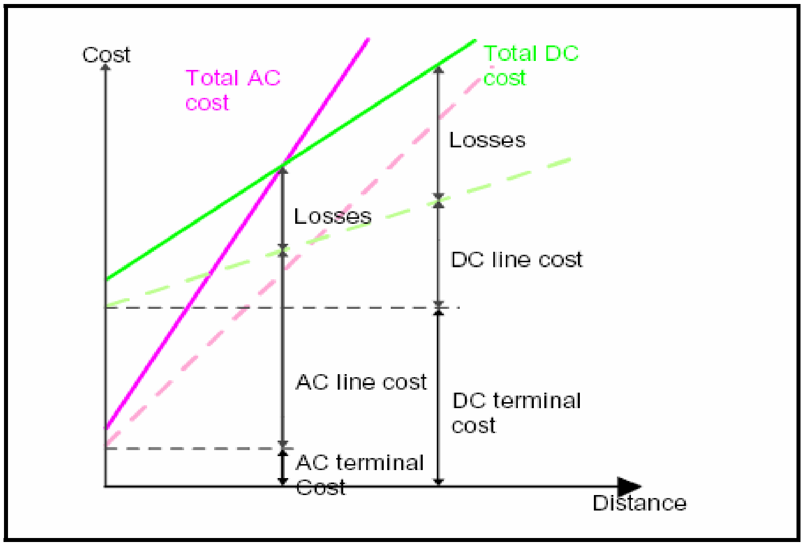


Figure I.3: The effect of transmission distance on AC and DC transmission line costs[25]

Figure I.4 shows the comparison of AC and DC cost curves for an illustrative case (this figure is for illustrative purposes only). In this example, for a 2000 MW line, AC is less expensive below 700 kilometers, and DC is less expensive above 700 km.

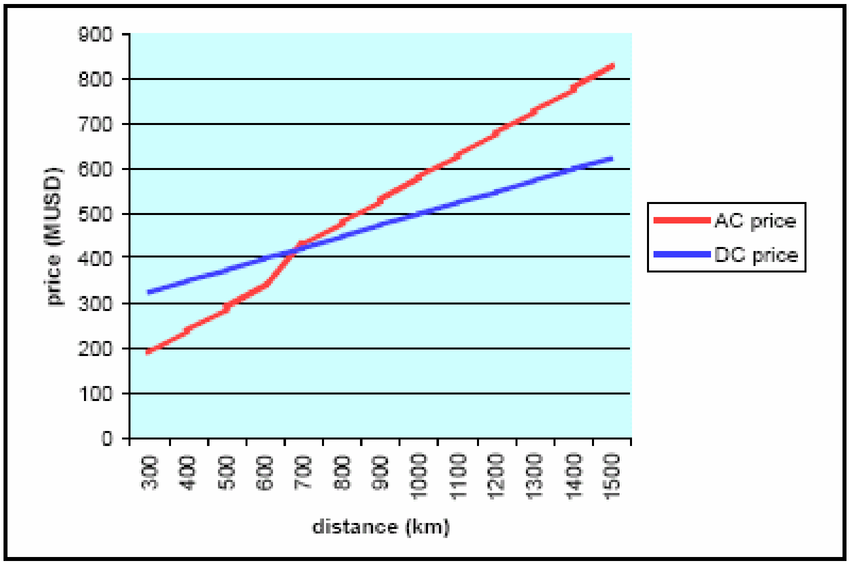


Figure I.4: AC and DC line costs for 2000 MW transmission line[26]

(b) <u>Transmitting power under water</u>

HVDC is preferred for undersea transmission. Undersea cables have a coaxial structure in order to minimize space requirements, but coaxial cables have a high capacitance. This presents a high reactive impedance to AC transmission, but DC is unaffected by capacitance and therefore can be used for high capacity, long-distance undersea cables.

(c) Asynchronous interconnections

HVDC is a viable alternative when synchronous AC connections are difficult or impossible due to the use of different system frequencies in the systems to be interconnected or other important system differences. As one expert has remarked, “the advent of DC connections has reduced the number of ‘islands’ that must consider themselves electrically isolated.” DC ties between different AC systems deliver some of the benefits of interconnection while avoiding many of the technical problems of synchronous operation. There are two general types of asynchronous interconnection: first, HVDC transmission over some distance, between two converter stations connected at either end to an AC system; second, HVDC “back-to-back” interconnection to AC systems on either side, without any intervening transmission. Back-to-back connections have sometimes served as a stepping stone to a later full synchronous interconnection.

In addition to the three applications above, there are other reasons HVDC interconnections are used. A key one is that HVDC carries more power for a given conductor size. Because of this, in situations where existing transmission capacity is constrained, HVDC is an alternative to an AC transmission upgrade. Conversely, to provide a given transmission capacity, HVDC lines, towers, and rights-of-way can be smaller than a comparable AC system, reducing the line’s environmental footprint. Another major advantage is that the solid-state controls of HVDC systems offer complete control over the direction of power flow, without unpredictable loop flows. The direction of flow can be reversed, and operating voltages can be reduced if necessary. The track record of HVDC indicates high reliability and availability and has the advantage that in a bipolar system one pole can operate even if the other pole is not operational due to maintenance or an outage. Also, HVDC does not increase fault currents in the network to which it is connected, so new circuit breakers are not required in the rest of the system. HVDC systems, however, are difficult to operate with more than two, or at most three, terminal connections to AC transmission systems, so that HVDC systems are not an optimal choice if power is to be supplied to several intermediate locations along a power line route[27].

2. Technical considerations with HVDC systems

(a) Components of an HVDC system

The main components of an HVDC system are the transmission line and the converter stations at either end of the interconnection. The heart of the converter station is the converters themselves, which are composed of high-voltage solid-state “valves” that perform the AC to DC and DC to AC conversions. The valves are air-insulated, water-cooled, and controlled by optical signals from fiber optic devices (since the valves operate at extremely high voltage and any physical connection to a grounded object, such as a wire leading back to a control room, would immediately become a short-circuit path). Converter stations also include transformers to convert to and from the AC transmission voltage to which the DC link is attached. Finally, converter stations include filters on both the AC and DC sides. Figure I.5 shows a schematic of an HVDC converter station.

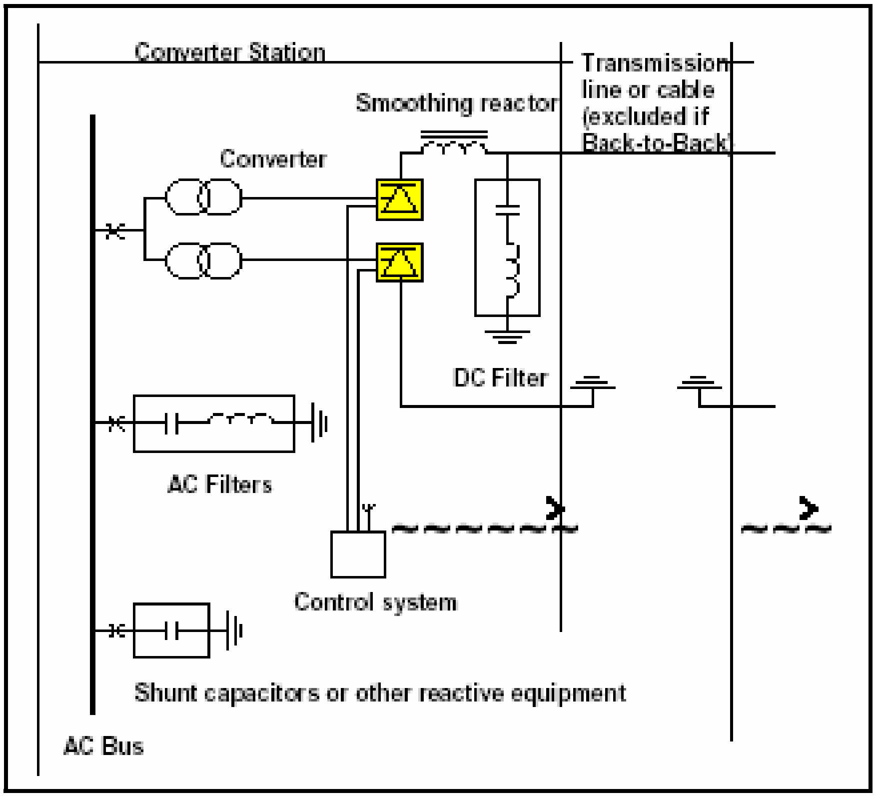


Figure I.5. Schematic of an HVDC converter station[28]

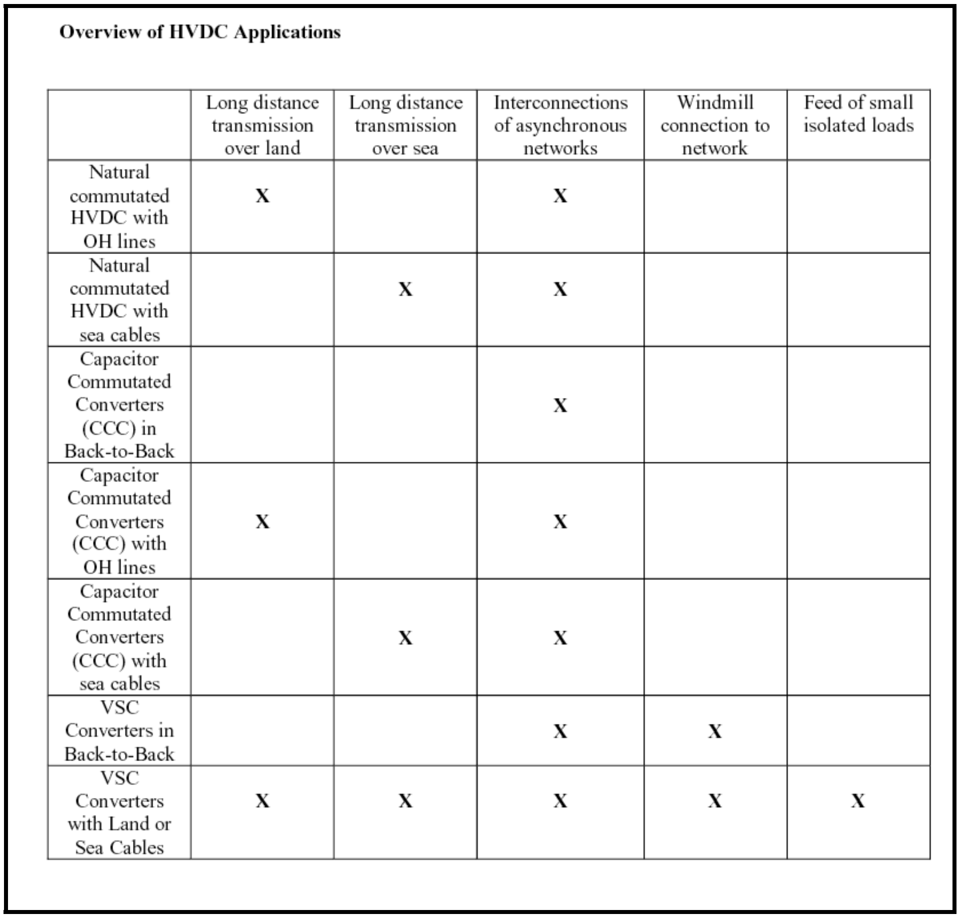
Overhead HVDC transmission lines can usually be easily identified because they have two conductors per circuit, rather than three as in the case of AC. Normally these lines are bipolar, that is, the two conductors have opposite polarity (e.g., +/- 500 kV). DC conductors are made from the same materials as AC conductors. Cables used for undersea transmission come in two varieties, solid and oil-filled.

(b) Choice of converter technology

An important issue in HVDC systems is the choice of converter technology. (AC to DC conversion is often called rectification, and DC to AC conversion is often called inversion. However, the term conversion is applied to both operations.) There are three types of converters:

(1) Natural commutated converters are the most common variety. They use solid-state device called thyristors, which are connected in series to form valves, which operate at the frequency of the AC grid, either 50 or 60 Hz;
(2) Capacitor commutated converters, which have capacitors inserted in series between the valves and transformers. They improve the performance of converters connected to weak networks;
(3) Forced commutation converters, which use rapidly switchable solid-state devices. One variety is the voltage source converter (VSC), composed of high-voltage transistors called IGBTs. The VSC performs conversion at very high frequencies, using a method called pulse-width modulation. This gives the VSC a very high degree of control over the incoming and outgoing waveform, allowing it to change power angles, control both real and reactive power, and maintain high power quality.

Figure I.6 shows the suitability of the different converter technologies for various applications.



Overview of HVDC Applications

	Long distance transmission over land	Long distance transmission over sea	Interconnections of asynchronous networks	Windmill connection to network	Feed of small isolated loads
Natural commutated HVDC with OH lines	X		X		
Natural commutated HVDC with sea cables		X	X		
Capacitor Commutated Converters (CCC) in Back-to-Back			X		
Capacitor Commutated Converters (CCC) with OH lines	X		X		
Capacitor Commutated Converters (CCC) with sea cables		X	X		
VSC Converters in Back-to-Back			X	X	
VSC Converters with Land or Sea Cables	X	X	X	X	X

Figure I.6: Applications of different HVDC technologies[29]

(c) Proximity to parallel AC lines

Parallel operation of high-voltage AC and DC lines in close proximity can create control problems. This must be considered in any siting decisions.

(d) Reactive power consumption

Natural commutated converters consume a substantial amount of reactive power in the conversion process, and may require reactive power compensation on the AC side. VSCs by their nature do not consume reactive power.

(e) Harmonics

The process for converting AC to DC power, and vice versa, involves rapid switching, which generates various harmonics that can reduce AC power quality and interfere with telecommunications facilities. AC filters are needed especially to eliminate harmonics of order 11, 13, 23, and 25; the amount of filtering necessary depends on the kind of converter technology employed.

(f) Operation and maintenance

Because of the high voltage environment associated with them, HVDC systems are designed for remote operation. Relatively few people can operate HVDC links from a central location. The maintenance requirements for HVDC transmission lines are comparable to those for high voltage AC lines. Turnkey systems (where a supplier builds an HVDC system, then turns it over to a line operator) are common, and the supplier should provide the necessary training and support to utility personnel. One week of maintenance per year is the typical anticipated outage time for HVDC systems.

3. HVDC projects worldwide

The highest capacity HVDC interconnection in the world at present is a bipolar +/- 600 kV line transmitting 6300 MW of power from the Itaipu dam on the Brazilian-Paraguayan border into Brazil over a distance of 800 km. HVDC was selected as the technology for this transmission project for two reasons: first, because of the great distance between the dam and demand centers and second, because the dam generates power at 50 Hz, while Brazil has a 60 Hz power system. The longest HVDC link currently operating is the 975 km line carrying power from China’s Three Gorges Dam. China also has the HVDC link with the highest power per pole, at 1650 MW. Figure I.7 below shows the location of major HVDC projects worldwide.

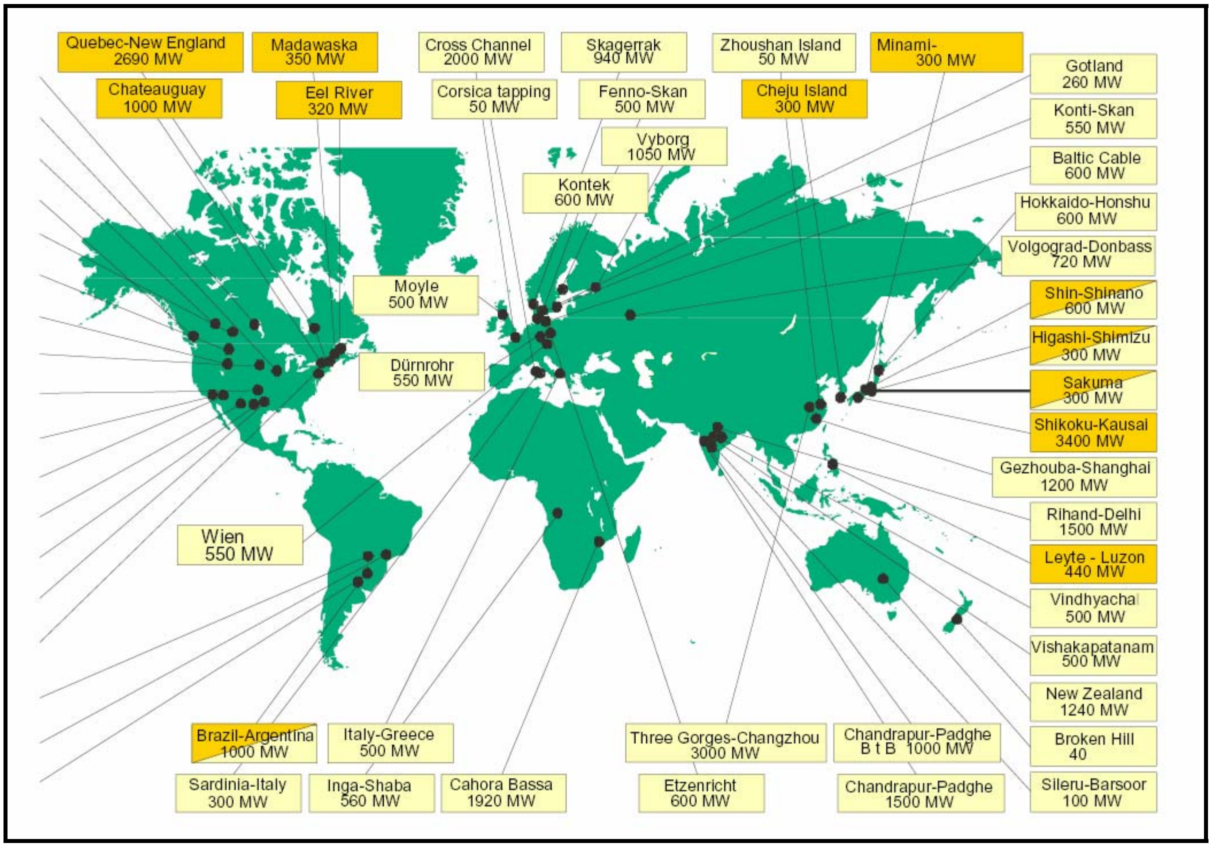


Figure I.7: HVDC projects worldwide. Lighter boxes are 50 Hz power systems, darker boxes are 60 Hz power systems[30]

E. PLANNING AND MODELING OF INTERCONNECTION TECHNICAL PARAMETERS

1. Planning steps

There are typically a number of distinct stages in the technical design of an interconnection project (although some of these stages may be combined or their order changed). These stages include:

(a) **Preliminary electricity supply and demand estimates**, usually based on resource planning and regional market pricing simulations. Project owners make quantitative estimates of time-dependent electricity supply and demand and potential magnitudes of power exchanges between the systems to be interconnected;

(b) **Technical specification**. Project owners provide potential designers/ contractors with general specifications, including the amount and direction of power to be transmitted, temporary overload levels, voltage levels, distance and terrain, and environmental requirements. Details on the technical status and operations of the different systems must also be provided;

(c) **Conceptual design**. Potential project designers/contractors provide project owners with a conceptual design for the interconnection, including the preliminary determination of AC or DC interconnection, overhead lines or cable, conductors, support structures, transformers, reactive compensation, substation location and design. For DC systems, a conceptual design will also include commutation method and filtering.

(d) **Tendering**. Potential designers/contractors tender offers to design and/or build the interconnection infrastructure to project owners, followed by review, negotiation, and approval;

(e) **Final design**. After approval of design/selection of contractors, the project design is finalized. Often, tendering and final design are an interactive process between designers/contractors and the project owners, sometimes also involving other interested parties.

2. Modeling requirements for transmission interconnections

During the project planning process, the design of the technical and operating parameters of an interconnection requires extensive computer modeling to ensure that the interconnection and the systems it connects provide reliable and economical service. The types of modeling required include the five methods discussed below.

(a) Power flow modeling

The most important single class of tools in power system engineering is that of power flow models, also called load flow models. These models are used to compute voltage magnitudes, phase angles, and flows of real and reactive power through all branches of a synchronous network under steady-state conditions. Power flow models account for loop flows and make it possible to understand how much power will actually flow on transmission lines under a given set of circumstances. Modelers vary the initial conditions (for instance, adding a proposed new generator to the network) and determine the impact on power flows throughout the system.

A standard reliability requirement is that utilities meet the "n-1" criterion, in which the system is able to continue to supply all loads despite the loss of a large generator or the outage of a large transmission line. These “contingencies” are modeled with a power flow model, and if the model results indicate a problem, planners and operators must address it, typically by adding new generation and/or transmission capacity, or by changing operational procedures.

Running power flow models requires that each bus and line in the system be thoroughly described, requiring a great deal of input data. The real and reactive power consumption at each load bus, the impedance of each line and transformer, and the generating capacity of all generators must be known.

Power flow models are used by the North American Electric Reliability Council (NERC) to calculate a power transfer distribution factor (PTDF) for individual power transfers. The PTDF shows the incremental impact of a power transfer from a seller to a buyer on all transmission lines, as a percentage of their transfer capacity. If a line is overloaded, transactions that have PTDF values greater than 5 per cent on the overloaded line can be curtailed[31].

(b) Optimal power flow (OPF) modeling

Optimal power flow models take the outputs of power flow models and analyze them according to user-defined *objective functions*, such as least cost or minimization of transmission loading. Where the ordinary power flow model provides only engineering information (voltage, power, and phase angle, for example) OPF models assist operators in ranking alternatives according to economic and other criteria.

(c) Short circuit modeling

Short-circuit models are used to compute fault currents for various kinds of short circuits (phase-to-phase and line-to-ground). The results of short-circuit models are used to determine the required specifications for protection equipment such as circuit breakers and relays, and to determine the proper settings for relays to clear faults.

(d) Dynamic stability modeling

Dynamic stability models are used to determine whether the synchronous machines in a power system (namely the generators and motors) will remain in synchronism in the case of a disturbance, for example the loss of a generator or transmission line, a fault, or a sudden increase in demand. The models work by calculating the angular swings of synchronous machines during a disturbance, and determining whether they will remain within an envelope of stable operation.

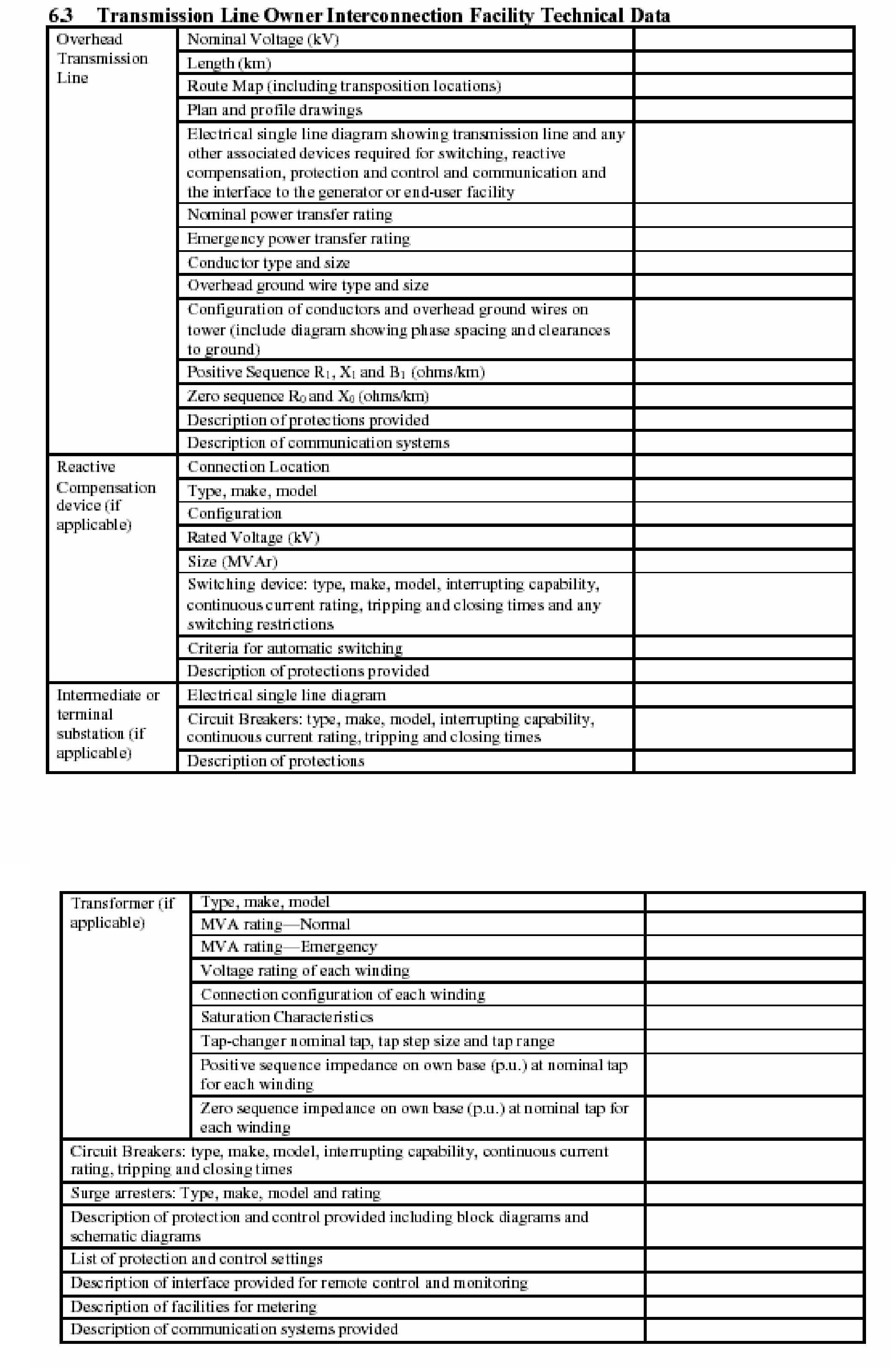
(e) Transient modeling

Transient models are used to compute the magnitude of transient voltages and current spikes due to sources such as lightning and circuit switching. The model results are used to specify the insulation requirements for lines and transformers, to determine grounding schemes, and to determine surge arrester specifications.

3. Data requirements for planning

The exchange of data among the owners/operators of the systems to be interconnected regarding the technical characteristics and requirements of their respective systems is essential from the outset of an interconnection project. The need for transparency and for the development of mutual understanding cannot be overemphasized. An example of the kinds of technical data that are typically exchanged in an interconnection project can be seen in Table I.1.

Table I.1: Sample of technical data requirements for interconnection[32]



6.3 Transmission Line Owner Interconnection Facility Technical Data

Overhead Transmission Line	Nominal Voltage (kV)	
	Length (km)	
	Route Map (including transposition locations)	
	Plan and profile drawings	
	Electrical single line diagram showing transmission line and any other associated devices required for switching, reactive compensation, protection and control and communication and the interface to the generator or end-user facility	
	Nominal power transfer rating	
	Emergency power transfer rating	
	Conductor type and size	
	Overhead ground wire type and size	
	Configuration of conductors and overhead ground wires on tower (include diagram showing phase spacing and clearances to ground)	
	Positive Sequence R_1, X_1 and B_1 (ohms/km)	
	Zero sequence R_0 and X_0 (ohms/km)	
	Description of protections provided	
	Description of communication systems	
Reactive Compensation device (if applicable)	Connection Location	
	Type, make, model	
	Configuration	
	Rated Voltage (kV)	
	Size (MVAr)	
	Switching device: type, make, model, interrupting capability, continuous current rating, tripping and closing times and any switching restrictions	
	Criteria for automatic switching	
	Description of protections provided	
Intermediate or terminal substation (if applicable)	Electrical single line diagram	
	Circuit Breakers: type, make, model, interrupting capability, continuous current rating, tripping and closing times	
	Description of protections	
Transformer (if applicable)	Type, make, model	
	MVA rating—Normal	
	MVA rating—Emergency	
	Voltage rating of each winding	
	Connection configuration of each winding	
	Saturation Characteristics	
	Tap-changer nominal tap, tap step size and tap range	
	Positive sequence impedance on own base (p.u.) at nominal tap for each winding	
	Zero sequence impedance on own base (p.u.) at nominal tap for each winding	
Circuit Breakers: type, make, model, interrupting capability, continuous current rating, tripping and closing times		
Surge arresters: Type, make, model and rating		
Description of protection and control provided including block diagrams and schematic diagrams		
List of protection and control settings		
Description of interface provided for remote control and monitoring		
Description of facilities for metering		
Description of communication systems provided		

4. Software tools

Table I.2 lists several examples of common software packages used for modeling power flow, optimal power flow (OPF), dynamic stability, available transfer capacity (ATC), and fault analysis. The table also includes examples of software used for integrated economic and resource planning, and SCADA software. This table by no means presents an exhaustive list of the software available to address these needs, nor does DESA or the authors make any claims or recommendations regarding these software tools—the table presents examples for reference only.

Table I.2: Power system simulation software

Company	Software	Function
PowerWorld Corporation	PowerWorld Simulator	power flow, OPF, transfer capacity
http://www.powerworld.com/products/simulator.html		
General Electric	PSLF	power flow, dynamic simulation, fault analysis
http://www.gepower.com/prod_serv/products/utility_software/en/ge_pslf/index.htm		
Siemens	PSS/E	power flow, OPF, dynamic simulation, fault analysis, transfer capacity, pricing
http://www.pti-us.com/PTI/software/psse/index.cfm		
ABB	SIMPOW	Power flow, dynamic simulation, fault analysis
http://www.abb.com		
General Electric	MARS	interconnected system reliability
http://www.gepower.com/prod_serv/products/utility_software/en/ge_mars.htm		
ABB	Network Manager	SCADA software
http://www.abb.com/powerT&D		
General Electric	XA/21	SCADA software
http://www.gepower.com/prod_serv/products/scada_software/en/downloads/xa21_overview.pdf		
LCG Consulting	UPLAN	integrated planning, market price simulation
http://www.energyonline.com/products/mpm.asp		
Global Energy Decisions	ProSym	integrated planning, market price simulation
http://www.globalenergy.com/detailed-zonal.asp		
OLADE and IADB	SUPER	generation and interconnection planning
http://www.worldbank.org/html/fpd/em/power/EA/methods/mtmpspob.stm		
ICF Consulting	IPM	integrated planning, market price simulation
http://www.icfconsulting.com/Markets/Energy/ipm.asp		
Operation Technology, Inc.	ETAP	integrated analysis tool for design, maintenance, and operation of electric power systems; includes modules for HVDC and many other functions
http://www.etap.com/products.htm		

An example of a software tool for Power Flow modeling with graphic interface features is the PowerWorld Simulator. Figure I.8 shows a "screen shot" of a PowerWorld simulation of a small network with 9 buses containing both load and generation. The circles with numbers inside indicate the percentage of transmission capacity of each transmission link that is in use under the given scenario. The visual interface helps operators and planners understand the impact of adding or removing generators and transmission lines, or of large changes in real or reactive power consumption by loads.

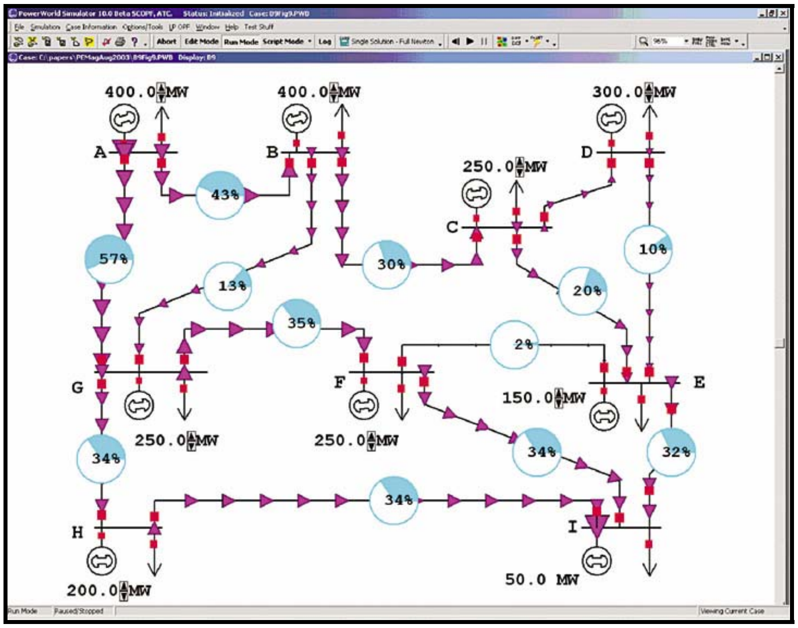


Fig. I.8: PowerWorld display of transmission loading on small 9-bus system[33]

Figure I.9 shows another graphic interface of the PowerWorld simulator. This figure shows the Power Transfer Distribution Factor (see Section E.2, above) for a proposed power transfer in the north central United States. It illustrates the importance of parallel path flows in loading transmission lines far from the nominal sender and receiver.

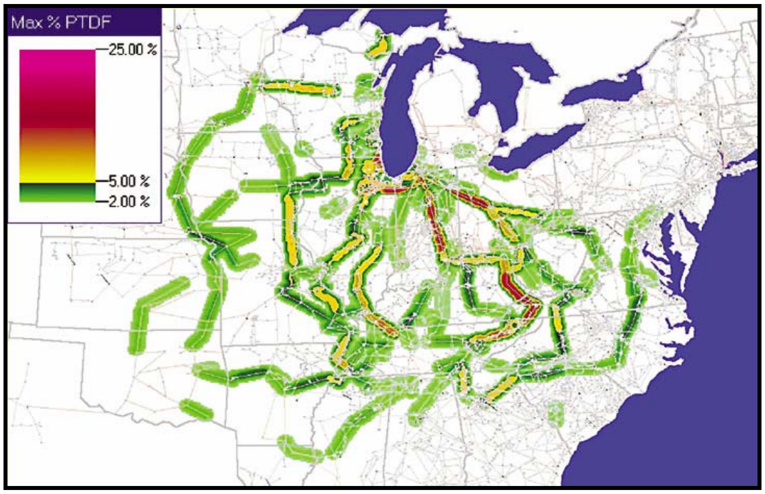


Figure I.9: PowerWorld display of PTDF for transaction in north central United States[34]

F. SUMMARY OF TECHNICAL ISSUES IN GRID INTERCONNECTION

Several basic technical issues must be addressed early in the planning process for a grid interconnection. Will the interconnected systems operate synchronously or asynchronously? What are the magnitudes and directions of the anticipated power flows? What physical distance and terrain will the interconnection span? What are the key technical and operating differences among the systems to be interconnected?

For AC interconnections, key design and operating issues are related to the constraints on transmission capacity, which include thermal limits, stability limits, and voltage regulation. Where there are liberalized electricity markets, these constraints become more severe as systems are operated closer to capacity. FACTS and HVDC options should be considered as alternatives or complements to traditional transmission upgrades. Simulation software is an essential tool for planning and operating an interconnection. For modeling to be effective, however, extensive technical data must first be gathered and shared between systems, and personnel must be trained. Grid interconnections require a careful calculation of costs, benefits, and risks. Technical planning of a grid interconnection should be coordinated with economic, organizational, legal, and political aspects of a potential interconnection project from the outset of project consideration.

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[26] Ibid., p.6.

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[28] R. Rudervall, J. Charpentier, and R. Sharma, op.cit., p.3.

[29] Ibid., p. 9.

[30] Ibid., p. 19.

[31] A word of caution regarding modeling results from an experienced transmission engineer: "I have found very poor correlation whenever I checked the studies made a number of years in advance against what actually happens in a transmission system. Often a planning study might indicate a 400 MW loading on a line that is really loaded 200 MW for a specified load level and condition. The actual flow patterns are usually quite different from those predicted by load flow studies. The generation in service is never quite what was used in the study. There are some units out that had not been anticipated; there is always some generator maintenance contrary to the planning assumption that no generator maintenance will occur at heavy load times. The generation dispatch is different from what was assumed in the study; the fuel costs are different; the forced outages are different; the heat rates are different. The peak load that occurs is different from the one used in the study. The load distribution is different; it has come in one area when it had been forecast in another area… The message here for the transmission system planner or system designer: the transmission system should provide the flexibility to meet changing conditions." John A. Casazza, "Measuring Use of Transmission", The Evolution of Electric Power Transmission Under Deregulation: Selected Readings, J. Casazza and G. Loehr, eds., (Piscataway, NJ, IEEE, 2000), p.95.

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II. ECONOMIC AND FINANCIAL IMPACTS OF GRID INTERCONNECTION

A. INTRODUCTION

Arguably the primary reason for developing an electric grid interconnection between countries is to reduce the overall combined economic costs of supplying electricity services in the interconnected countries—at least relative to non-interconnected systems[35]. Energy trading between nations offers significant direct economic benefits but also in most cases requires significant economic and financial outlays. There are also potentially many indirect economic benefits of a grid interconnection for one or more of the countries involved, as well as potential indirect economic costs. Pricing of traded electricity requires careful consideration and negotiation if all parties are to benefit. Making sure that the economic costs and benefits are shared fairly between project partners (and among various stakeholder groups within nations) requires that economic and financial structures be in place before (typically) expensive interconnections can begin operation.

The "E7" Group of Utilities describes some of the economic benefits of interconnection as follows:

> "The pooling of resources and the interconnection of isolated electric power systems allow optimum use of available resources. They will be instrumental in achieving reductions in the operating cost of the generation mix, increasing the generation capacity margin and, conversely, reducing the need for investment in peak capacity. Lower production costs and/or lower investments in generation, achieved through the interconnection of electric power systems, should have an impact on rates to the customers' advantage. Improved electric power systems reliability will foster an increase in quality of service and a reduction in power interruptions that too often lead to productivity losses in the commercial and industrial sectors, affecting average regional manufacturing costs and, finally, the national gross domestic product (GDP). Pooling electricity resources is crucial if the electric power systems are to fully contribute to sustainable development." [36]

Careful planning and modeling of options (with consideration of the economic costs and benefits in each of the countries potentially involved in an interconnection) is required in order to ensure that the interconnection project provides significant net benefits to the countries concerned. In some cases, this may include modeling of other energy resource transport options in addition to transport of electricity. A report prepared by the World Energy Council, for example, compares the costs of transmitting electricity from remote gas-fired generation to electricity markets to the costs of transporting gas to generation constructed near electricity markets. This particular analysis found the overall costs of providing electricity to be less, for most combinations of variables when transport distances were above 1000 km or so, if the gas was converted to electricity at the gas field rather than near the consuming area[37].

B. POTENTIAL ECONOMIC AND FINANCIAL BENEFITS OF INTERCONNECTION: POWER SYSTEM

The potential economic benefits of interconnection for the power systems of the interconnected countries (considered either individually or together) include fuel costs avoided by the interconnection, avoided generation capacity costs, avoided operating costs, and avoided costs for transmission system improvements. Savings in these elements come about largely because the operation of the interconnected system can (to a degree) be coordinated to optimize the use of resources on both systems to meet the loads on both systems. Income from power sales, of course, is also a key direct benefit of interconnections for exporting countries.

1. Avoided fuel costs (where country providing power is using lower-cost resources)

Grid interconnections offer opportunities to reduce generation fuel costs per unit of electricity delivered by allowing generating plants with low fuel costs to be connected to loads, and also by allowing plants with low fuel costs to run more by presenting a flatter demand load curve.

Grid interconnections, and particularly international interconnections between countries with varied resources, offer the option of siting power plants where generation resources are located and transporting power from those areas to load centers. Key examples of such resources (particularly in regions such as Africa, Latin America, and the Russian Far East) are hydroelectric resources, which often are located in areas remote from major populations. Other examples of power plants with low fuel costs, however, include mine-mouth coal-fired power plants, natural gas from gas fields where pipeline transport to markets is undeveloped or problematic (or from oil fields where gas has previously been flared), and in some countries, nuclear power. For resources such as hydroelectric power, (and, perhaps within a few decades, large-scale solar, wind, and tidal power) power line transport is arguably the only current method of transporting large amounts of energy from where it is converted to distant consumption centers[38]. For resources such as coal and natural gas, conversion to electricity and transport over power lines (including interconnections) must compete with other methods of transporting the fuels to end-users and/or power plants closer to load centers.

A grid interconnection, whether it is between nations or between otherwise largely isolated grid systems within one country, effectively increases the size and scope of both the electricity supply system and the electricity demand that must be met. In any power system, a "load curve" describes the relationship between the power (in MW, for example, or in fraction of peak power demand) to be supplied to meet overall demand and the number of hours in a year when power is at a given level. With an interconnection, the areas joined may be different enough in the mixes of consumers served and/or the timing of high and peak electricity demand so as to result in a "flattening" of the load curve, that is, an overall reduction in the ratio of annual peak hours to non-peak hours[39]. If the countries (or areas) to be interconnected have peak power demands at different times of the day or in different seasons, once the systems are interconnected, the baseload generation plants (typically those units with lower fuel and other running costs) can run a larger fraction of the time (at a higher capacity factor), thus allowing plants with higher fuel costs to run less. Further fuel savings can accrue because power plants are often more efficient when run at or near full capacity for more hours at a time In addition, having an interconnection may allow the construction of larger power plant units, which may (up to a point) have higher efficiencies than smaller units. The "E7" Group of Utilities describes the benefits of flattening the load curve as follows:

> "Once the former isolated power systems are interconnected, the overall load and the load factor increase: the load curve is flattened. Flattening the load curve will make it possible, in the short term, to maximize the use of the low fuel cost units, thus decreasing the overall fuel cost. At the same time, it will increase the capacity margin of the overall power system. In the long term, it may permit the introduction of bigger size units in the power system, thereby capturing economies of scale. Not accounting for the possible economies of scale in the generation sector, flattening the load curve is *per se* a strong incentive for interconnecting isolated networks."[40]

Depending on the structure of the interconnection and on the characteristics of the interconnected countries, generation fuel costs may be avoided on a net basis in just one or in more than one of the interconnected nations. If the interconnection is primarily an export-import arrangement, overall fuel costs will be lowered in the importing country, though fuel costs per unit of electricity generated could fall in both importing and exporting countries if the interconnection allows the exporting country to use its low-fuel-cost generation more. Fuel-cost savings may also have effects "upstream" in the fuel chain in the importing country as, for example, reduced need for generation fuel also reduces the need for fuel production (for example, coal mining) capacity, with the reduced need for fuel production capacity having its own economic and financial benefits.

2. Avoided generation capacity costs

In addition to avoiding fuel costs, a major incentive to pursue the interconnection of power systems is to avoid costs for new generation. Generation capital costs can be avoided through interconnection by a combination of replacement of domestic capacity with capacity from power imports, through reduction in power plant siting costs, through economies of scale in generation, through flattening of the load curve and related capacity trade-offs between countries, and through reduction in required reserve margin.

The most obvious way that a grid interconnection can result in reduced capital costs of electricity generation capacity is by displacing the need for new domestic capacity in an electricity importing country. In this case, depending on how the capital investment in the interconnection infrastructure itself is designed, the importing country may be spared or be able to defer the financial burden of the costs associated with new domestic power plants (needed for energy, serving peak power needs, or spinning reserves), making payments for electricity consumed from the interconnection instead[41].

Savings through economies of scale in power generation capital costs come into play in a grid interconnection when the interconnection allows the development of larger power plants than could be supported before interconnection by the demand in any one of the countries in the project. As noted by the "E7" Group of Utilities:

> "At the level of the power generation unit, for a given technology (diesel engines, steam turbines, combustion turbine, wind turbine, etc.), increasing the unit size reduces the unit investment cost, increases efficiency and reduces labor cost per kWh generated by the unit. The capacity at which these economies of scale are exhausted depends on the technology: around 1,000 MW for nuclear units, 600 MW for steam turbines, 300 MW for combined cycle units, and 50 MW for diesel engines. For a given technology, increasing the size of a unit generally entails technical barriers that will challenge the

> R&D department of electric plant manufacturers....Economic gains may also arise from the operation of several units on the same site. For hydroelectric power plants, these gains arise from the fact that civil works for the dam account for most of the investment cost of the hydroelectric power plant. Spending the additional investment cost of a turbine is not commensurate with the up-front cost of civil works. Hence, the full exploitation of a hydroelectric potential is often an important incentive for interconnecting isolated networks." [42]

"Flattening the load curve" by combining loads from two or more systems may also allow savings in capacity costs by allowing peaking capacity in one nation to effectively serve peaking needs in another, if the times and/or seasons of peak power requirements in the interconnected service territories do not significantly overlap. The net result is that less overall peaking capacity (and perhaps less intermediate-load capacity as well) may be needed. This sort of synergy has been noted between the grids of the winter-peaking Russian Far East and that of its potential electricity trading partner, the summer peaking Republic of Korea[43]. When countries are interconnected with sufficient transmission capacity, more choices exist for the placement of new generating resources to meet the combined demand of the interconnected systems, allowing (theoretically) the more efficient use of available international investment funds for building new power plants[44].

Another aspect of connecting electricity systems is that there may be a reduced need for reserve capacity, as the larger, interconnected system may be able to supply electricity at acceptable levels of reliability with a lower reserve margin. Having a lower reserve margin (that is, reducing the ratio between overall peak demand and total available generating capacity) means that lower investments in capacity, in particular peaking capacity, are required.

It should be noted that reductions in capacity costs due to flattening the load curve, complementarities of peak times or seasons, and reserve margin impacts in particular, and economies of scale impacts to an extent as well, depend on there being enough capacity in the interconnection to substantially affect capacity requirements. Fully realizing these benefits also depends on there being sufficient internal transmission capacity in the interconnected countries to allow the benefits of the interconnection to flow to where peak demands are greatest. If transmission restrictions (whether physical capacity limits or restrictions on access of generators to transmission capacity) prevent power from the interconnection from flowing to some large demand centers, the overall capacity cost reduction from the interconnection is likely to be lower[45].

3. Avoided operating costs

When the addition of an interconnection causes changes in the way that power plants within one or more of the interconnected nations are operated and/or built, a savings in operating costs will likely accompany any savings in fuel costs and/or capital costs. These costs savings, which may occur in one or more of the interconnected nations, include savings in variable operating costs, which vary with the amount of electricity produced, and in fixed operating costs, which vary (at least somewhat) with the amount of generating capacity but not with the amount of generation in any given year. Variable cost savings include, among others, savings on chemicals for pollution control equipment, possibly spinning reserves costs, and savings on waste disposal costs; for example, if a coal-fired power plant is operated less due to an interconnection, the volume of coal ash to be disposed of and, hence, the costs for transport and disposal will be reduced. Fixed operating costs, including costs for some maintenance activities, plant labor costs, and other costs, are avoided primarily when the use of an interconnection reduces the need for capacity additions.

4. Avoided costs for transmission system improvements

In some cases, international grid interconnections may avoid national investments in transmission system improvements. When an interconnection, for example, allows existing or new electricity customers living in remote areas near international borders to be provided with electricity service, the costs that would have been incurred to connect those customers directly to the national grid will be avoided. An interconnection may be able to serve towns and cities in border regions through or near which the interconnection will pass more easily than service can be provided from the main power grids of the countries. Similarly, depending on how the interconnection is configured and on the configuration of existing transmission in the nations to be interconnected, the interconnection itself may serve to take the place of needed transmission reinforcement. In either case, the calculation of the net cost of the interconnection needs to take into account the difference between the long-term costs of the electric power systems of the interconnected systems with the interconnection in place and the costs of providing the same electricity service without an interconnection.

5. Income from power sales

For power exporting countries, income from power sales is a key economic advantage of power grid interconnections. To the extent that some or all of the power sales are paid for in hard currencies (dollars or euros, for example), the sales provide foreign exchange benefits as well. Income from power sales is most useful for national accounts, particularly in developing nations, in situations in which a significant portion of investments in generation can be made in local currencies and/or in which investments are financed by a third party, such as a private company, rather than by the government itself.

C. POTENTIAL ECONOMIC AND FINANCIAL COSTS OF INTERCONNECTION: POWER SYSTEM

Each of the potential direct economic benefits of grid interconnection described above has counterpart costs that must be considered in an accounting of the net benefits of interconnection. These include additional generation fuel costs, additional capital and operating costs, connection infrastructure costs, costs of operating the grid interconnection, costs of needed power system upgrades, and costs of power purchases.

1. Costs of fuel used to generate exported electricity

For interconnections built in large part to provide a means of exporting power, the costs of the fuel used to generate power for export must be considered. Fuel costs for hydroelectric, solar, geothermal, wind or (to a lesser extent) nuclear power plants may be negligible, but the costs for any additional coal, oil products, or gas used to generate power for export must be counted against fuel costs avoided in the importing nation. Fuel costs should be calculated so as to include any fuel-chain costs related to fuel provision. These will include, for example, costs for developing coal mines and for mining itself, costs for gas extraction or for gas import facilities, and other similar costs. In instances where an open market exists for the fuels used for electricity generation, a market price may be a suitable substitute for a full accounting of fuel-chain costs of providing fuels, but in many countries where subsidies, often hidden, obscure the true costs of fuel provision, a more detailed approach to the costing of fuel inputs to power generation may be required. A paper from the Workshop on Regional Power Trade (held in Kathmandu, Nepal, in March 2001) makes the following point about the need for careful economic analysis of projects in regions where electricity and fuel price subsidies have been common:

> "Electricity prices often have been used as the vehicle to promote Government social policies through subsidies to particular classes of customers, cross subsidies between classes of customers, non-sustainable tariff levels to the benefit of all customers, fuel subsidies to generating facilities, and non-commercial capital repayment conditions. Regional trading that may appear to be economically advantageous given current prices in the sending and receiving areas may appear less attractive when such subsidies are removed or when a more commercial terms and conditions are applied with respect to the generation sector." [46]

2. Costs for power plants used to generate exported electricity

If new power plants are constructed to generate electricity for exports as a part of the interconnection project, the capital and operating costs of those projects represent a net cost to the interconnected system, relative to the cost of the non-interconnected system. Although potentially reduced somewhat on a per-unit basis due to economies of scale derived from being able to sell electricity to a wider market, the additional costs of new generation also may represent significant financial costs to the exporting country, particularly if much of the equipment or materials for the export power plants must be imported and/or if the government of the exporting country must finance or make hard currency payments on a loan to finance the infrastructure. If the power plants are mostly built and financed by a third party with limited input of funds or guarantees by the host government, then export power plants may constitute less of a financial burden to the government itself.

3. Costs of interconnection infrastructure

Perhaps the most obvious direct cost of an international grid interconnection is the cost of the power line joining the grid systems. Power line costs include:

(a) Costs of electrical conductors and insulators;
(b) Costs of purchasing and erecting transmission towers, and of clearing rights-of- way;
(c) Costs of substations and transformers to connect grids to the power line;
(d) Costs of power line control hardware and software;
(e) Costs of any special interconnection hardware, such as AC to DC and/or DC to AC converters, when the interconnection links must provide a degree of isolation between two systems with very different operational parameters, or when a long-distance DC power line is part of the interconnection.

All of these costs may vary substantially from project to project. Costs depend greatly on the terrain to be traversed, the vegetation present, the characteristics of existing rights-of-way and requirements for rights-of-way, and the hardware needed for system interfaces. As one example comparison, the "E7" Group suggests that "the unit investment cost of a combustion turbine, for instance US$250/kW, is of the same order of magnitude as the investment cost of a 1000 kilometer-long Direct Current (DC) transmission line with a 3000 MW capacity" [47]. Economies of scale in power transmission are significant, with higher-voltage power lines costing less, per MW of power transferred, than lower-voltage lines, and with the possibility of carrying more than one set of conductors on a single set of towers and in a single right-of-way for further cost reduction.

The financial cost of the interconnection to the countries involved depends on arrangements for financing (for example, whether the power line connecting the countries is paid for by one or more of the interconnected countries directly, financed through an international financial institution, or is privately financed), and what the arrangements are for repaying the debt on the transmission line and related infrastructure.

One potential means of reducing the financial cost of qualifying interconnections is through the Clean Development Mechanisms (CDM) of the Kyoto Protocol to the United Nations Framework Convention on Climate Change. CDM, in theory, allows countries (typically industrialized counties) to receive credit for a portion of the reduction in greenhouse gas emissions (relative to a specified “baseline” level of emissions) brought about by projects in developing countries. The “E7” Group of Utilities describes the somewhat uncertain potential for financing interconnection projects with CDM funds as follows:

> “Many of the investments involving an interconnection line should qualify since either they will favor a better dispatch of the generation mix — likely to reduce the consumption of fossil fuels and, thereby, reduce CO_2 emissions of the power system — or facilitate the development of hydroelectric power plants that will replace thermal power generation.....However, the current stand among the experts devising these CDMs is project-wise, irrespective of the project’s contribution to the emissions of the whole power system. For the time being, these experts have not devised anything relative to the baselines for qualifying transmission lines that would permit a better dispatch of the generation mix.”[48]

4. Costs of operating interconnection infrastructure

An additional element of the total accounting of direct costs and benefits of a grid interconnection is the costs of operating the grid interconnection itself. Operating costs include the costs of labor and supplies to maintain the power line, the rights-of-way, and the substations and other infrastructure, as well as the costs of running control centers that dispatch power to and from the interconnection. These costs are typically relatively small relative to the power plant fuel, capital and operating costs, and to the power line infrastructure costs.

5. Costs of power system upgrades

In some cases, countries participating in interconnection projects will find that upgrades to their national power systems will be required in order to be able to accommodate (technically and economically) the interconnection itself. For example, transmission systems may need to be upgraded and reinforced, and control systems (hardware and software) may need to be modernized. These changes certainly imply costs for each national transmission system, but the improved reliability and availability of power that the upgrades produce, even independent of any interconnection, will provide both direct and indirect economic benefits[49]. Last but not least, customer metering and billing systems may need to be upgraded to improve collections (so that power imports can be paid for) and to reduce or eliminate illegal consumption of electricity so as to assure that the costs of power delivered by the upgrade are compensated by payments from end-users. Each of these types of upgrades will yield dividends for the national economy—in the form of reduced electricity losses, better utility cash flow, less wastage of electricity (by consumers not paying for power), and a more equitable distribution of the benefits of electricity—but the upgrades will also require up-front investments in equipment, software, improvements in security of distribution and transmission systems, and training for network control and collections/accounting personnel[50].

6. Costs of power purchases

For a power importing country, costs of power purchased from the interconnection represent a direct cost to the power system that must be balanced against the types of direct savings described in section B, above, and the indirect net benefits described below. In many cases, power purchases from an interconnection will need to be made in (or partially in) hard currencies; this could represent a significant financial burden to an importing developing country, potentially exerting a drag on a country's balance of payments.

D. ECONOMIC AND FINANCIAL COSTS AND BENEFITS OF INTERCONNECTION: NATIONAL ECONOMY

In addition to the direct benefits and costs of the power systems to the connected countries, international grid interconnections also offer the potential for indirect economic benefits (and costs) related to the employment impacts associated with the construction of power plants and power lines, the impacts of improved power supply on local and national economies, and the impacts of net savings on power supplies.

1. Stimulation of local economies from construction and operation of transmission and generation infrastructure

As with other large infrastructure projects, such as pipelines, transport sector development, or the construction of major industrial facilities, the building of new power lines and power plants to feed them will typically result in significant short-term employment for laborers, engineers, and others in the area where the infrastructure is being built. As the workers who build a power line or power plant require support services (food, lodging, and other services), such projects also typically attract and provide employment for a community of vendors and others to serve those working on the project. While the creation of this local employment and the economic activity related to it may be beneficial to the area where the infrastructure is built in the short term, unless carefully planned it may also, run the risk of creating a "boomtown"—a town that grows and bustles with activity while the project is underway, but largely fades away, often leaving economic and social dislocation as well as environmental damage in its wake when the project is complete[51]. The "boomtown" syndrome is a clear example of non-sustainable economic development.

In the longer term, the ongoing operation of power plants and transmission lines will require a community of workers for day-to-day operation. Though the number of workers needed for ongoing operation of these types of facilities is far less than the number required during the construction phase, hundreds to thousands (for example, for a major nuclear plant) of workers may be needed, proving local employment on an ongoing and likely sustainable (if planned correctly) basis in both the operation of the facilities themselves and in the community that will be needed to provide support services for the workers[52].

2. Stimulation of local economies in importing nations through improved power supply

In nations that will import power or whose power systems will be stabilized by interconnections, a key indirect benefit of interconnections is the impact of more stable and (presumably) less costly supplies of energy on the local and national economies. To the extent that interconnections allow the electrification of areas that had previously lacked electricity, new electricity supplies can be expected to contribute to the local economy through improving the productivity of agriculture (for example, through the use of electricity instead of human or animal power for milling of grains), reducing the amount of labor needed for household tasks such as water provision (thereby leaving more time for home and small businesses and other productive activities), and making possible the development of other local industries. Similar benefits may accrue if the reliability of electricity supply is markedly enhanced. The improvement from a situation where electricity supplies are intermittent to a situation where electricity supplies are always or nearly always available makes the siting of new industrial capacity more attractive and feasible, contributing to the development of the local economy. Improved power supplies also benefit existing businesses and their employees; many businesses must shut down when power is unavailable, resulting in loss of income, wastage (in some cases, such as the food industry) of products or raw materials, and loss of employment[53]. New and/or better access to electricity for communities often means improved access to educational opportunities (such as the use of electric lights for study at night), and better health care (light for examination rooms, refrigeration for medicines) which may reduce productive time lost due to illness[54]. Grid interconnections may also allow developing economies to access needed additional electricity supplies faster than through development of domestic electricity sources, thus avoiding (to the extent possible) temporary shortages of electricity and the negative effects of such shortages on economic growth[55].

To the extent that there are net savings in overall direct power supply costs due to the interconnection (and assuming that those costs are passed on to electricity consumers in the form of reduced tariffs), there should be a stimulation of the local economy (where prices are lowered) through the "re-spending" effect. When the amount of money that a household must spend on grid electricity (or other forms of energy, such as batteries or lamp oil) declines due to tariff reductions, the household has more money to spend on other goods and services, and/or can devote a higher proportion of income to savings. In either case, the result may be enhanced local economic activity and enhanced investment in the means of production, both potentially assisting the process of sustainable development[56].

3. Economic benefits resulting from increased competition in electricity generation

Another possible economic benefit of grid interconnections is their role in spurring greater international and national competition in the power generation sector. Additional competition in the sector may serve the purpose of lowering both costs of electricity generation and lowering electricity prices, while improving efficiency and productivity. The economic benefits of such improved competition could accrue by allowing more domestic and foreign firms to enter the market, with the greater competition in electricity supply resulting in reduction in the price of electricity for end users (resulting in the types of economic stimulation described above). More domestic firms may be able to enter a market in a country receiving power over an interconnection due to the improved transmission access that the interconnection provides. Similarly, foreign generators (assuming favorable access rules) will have improved potential to send power to markets across borders, presumably at lower transmission costs. Another possible mechanism for bringing about increased competition is that an interconnection project brings with it a level of required increased transparency in financial dealings at the utility and governmental level that makes electricity pricing and market opportunities more obvious to potential generators. Countries with relatively few domestic market actors may be able to form a fully functioning electricity market only if interconnections are strong. This was noted in a study describing the "Baltic Ring" interconnection project for the Baltic region of Northern Europe:

> "In a number of cases, joint multi-national solutions are the only reasonable alternative for countries that want to achieve true competition, i.e. countries need one another to enable competitive solutions to perform well in practice." [57]

Of course, an opposite effect is also possible, as having a large transmission line in place may depress local wholesale electricity prices and/or saturate (in the short or long term) the market for additional capacity, both of which would tend to reduce private entrants to local, national, or cross-border electricity markets.

A special case of the impact of grid interconnections on competition in the electricity market is their impact on distributed generation. Distributed generation refers to small generation facilities (usually kilowatts to tens of megawatts), typically owned by electricity customers (though sometimes by third parties) and located on customers' premises, that allow on-site generation of electricity and sometimes heat as well, reducing transmission and distribution losses, and also reducing the need for transmission and distribution capacity (as well as for generation capacity in general). A grid interconnection can help to set up the market conditions whereby distributed generation can compete with utility resources, particularly in instances where an interconnection results in a change from a vertically-integrated, single utility structure. Conversely, on the negative side, the presence of low-cost power from an interconnection may make it more difficult for distributed generation to compete in the generation market.

Overall, the degree to which an interconnection brings with it enhanced competition in generation (for both large generators and distributed generation) and, through competition, reduces electricity prices (without compromising power quality or social or environmental qualities) depends on the degree to which the full costs of all alternatives are considered in planning the energy sector, and on the degree to which all relative costs are transparently included in market prices as much as possible.

In the European context, an observer from Electricité de France notes that though it is assumed that international electricity trade or the possibility of trade should drive down electricity prices, in practice a combination of insufficient cross-border interconnection capacity and a lack of harmonization of network access rules across the countries of Europe means that the market for electricity remains fragmented[58]. Thus, while interconnections may ultimately help to lead to a more competitive international market and better electricity prices for consumers, there are clearly a number of other considerations that come into play in determining the impacts of interconnections on electricity markets.

4. Benefits of interconnection dependent upon the structure of transmission capacity

It is not necessarily the case that an interconnection configured to bring lower-cost power to a country will bring significant direct economic benefits—avoided fuel, O&M, and capacity costs—to all of the regions in the countries that are interconnected. In many cases, internal transmission "bottlenecks" (points in the network where transmission capacity is inadequate) may prevent some or many regions of the interconnected countries from accruing significant benefits from the interconnection. In a detailed modeling study of the power systems of Northeast North America, Eynon and colleagues looked at the economic and technical benefits from the interconnection between the United States and Canada, and concluded (in part) "...that certain bottlenecks prevent all regions [of the US Northeast] from benefiting to the same extent" from regional interconnection[59]. This result underscores the need for thorough, well-informed economic and power flow modeling of the systems to be interconnected before interconnection is begun in earnest. Making sure that domestic transmission capacity is sufficient to allow good use of the interconnection is necessary to ensure that the interconnection investment is worthwhile.

E. PRICING OF ELECTRICITY TRADED BETWEEN NATIONS

A key economic consideration in any grid interconnection is how the electricity that will be traded will be priced. This includes consideration of what elements of energy and capacity will be priced, what basis or bases should be used for pricing, and what arrangements may be made for changing prices paid over time[60].

1. Elements to be priced

A grid interconnection is designed to move electrical energy and power from one grid to another. Within this general mission, however, the interconnection may provide several different related services, all of which may have their own pricing structure. The services sold over an interconnection may include:

(a) Transmission capacity, which may be sold to generators (or bulk purchasers of power) independent of any actual deliveries of power over the interconnection;
(b) Electrical energy, sold by generators to purchasers (in units of cost per MWh, for example);
(c) Delivered power, sold by generators to purchasers (in units of cost per MW, for example);
(d) Ancillary services, sold by generators and/or by the operators of the interconnection to the power grid or grids, and including services (such as spinning reserve, short-term regulation of grid stability, and electricity for "black start" of power plants) that allow for the smooth operation of grid systems and maintenance of power quality[61].

2. Potential bases for pricing

There are a number of different ways that prices for the services (including energy and power) to be provided by an interconnection may be valued and priced.

Prices can be based on *production costs* where, for example, the costs of electrical energy provided via an interconnection is by agreement equal to the cost of generating the power—including fuel, operating and capital costs expressed per unit of energy, plus the costs of delivering the energy to a designated transfer point (factoring in losses), and probably an additional amount for profit or return on investment. Pricing based on production costs requires a clear and transparent means for both parties agreeing to the pricing to review actual costs of production. Production cost pricing is probably more feasible for the pricing of energy, capacity, and power delivered than for the pricing of ancillary services. This cost-based method of determining average tariffs has been used for years in many jurisdictions in the United States, especially for determining tariffs to be charged to customers by regulated utilities.

Prices for the services provided by the interconnection can also be determined by consideration of *avoided costs*. In this case, the question is not what it costs to provide electricity via the interconnection, but what the electricity will be worth to the partner purchasing the electricity services. Here the costs of fuel, operations, capital expenditures on power lines and plants, and other cost elements that are avoided by the use of energy and power via the interconnection set the upper limit on the amount that can be paid for the services provided by the interconnection. Calculation of avoided costs depends on a consideration of what the future development (often fairly long-term development) of the power system would look like in the presence and absence of an interconnection when both "scenarios" provide the same energy services. This comparison, in turn, requires both a long-term forecast of energy demand and a long-term plan, at least in skeletal terms, of how demand will be met through supply additions and other system changes. The total costs avoided by using the interconnection instead of other means of providing electrical energy, power, capacity, and ancillary services are then divided by some measure of the services provided (capacity, power, or energy delivered) to calculate a unit price. The avoided costs method of pricing has often been used in the past in the United States to provide a rate, or sometimes an upper limit on the rate, that a distribution utility will pay for electricity provided by independent power producers.

In some, probably limited cases, the *costs of other forms of energy* that would compete with electricity provided by an interconnection may provide a ceiling price. For example, the cost of lamp oil or batteries for rural lighting may provide an upper bound on the value of electricity from an interconnection if rural lighting were the major intended market for electricity from the interconnection[62]. Similarly, if electricity from an interconnection were intended largely to provide power for a factory or mine, the cost of operating electric motors with energy from the interconnection would be compared with the costs of operating diesel motors. In most cases, however, electricity will serve a variety of end-uses with a variety of potential competing fuels, and the calculation of the value of electricity based on substitute fuels is not straightforward.

A final means of developing prices for electricity services provided by an interconnection is through *negotiation*. Negotiation of the prices to be paid for electricity services requires that each party to the negotiation have an understanding of its own costs of providing electricity services (either to its own customers in the absence of the interconnection, or to export customers via the interconnection) that is as complete as possible. Negotiation, however, does not require full disclosure of costs to the other party. Prices for electric energy, power, capacity, and ancillary services can be negotiated and agreed to through a long-term contract, or can be renegotiated periodically. For example, the Southern African Power Pool (SAPP) was originally designed as a "loose pool", with purchase arrangements between buying and selling utilities made on a bilateral basis via long-term contracts[63].

The extreme form of negotiated prices is an open market for electricity and electric services. Here generators (for example, those selling power through an interconnection) would offer blocks of power or energy at prices that might vary by the week, day, hour, or even minute, to be purchased (or not) by distribution utilities, groups of customers, or even individual (typically large) customers. Markets for electric energy, power, capacity, and ancillary services have been operated for several years in a number of jurisdictions in the United States and elsewhere. For markets to operate properly, a fairly large number of electricity sellers is required, with no one seller holding undue market power. The market may operate with a single buyer or with many buyers, but must operate under clear and specific rules (including rules for open access to transmission services) and procedures, under the auspices of an independent (or government-based) market operator, and with appropriate regulation. If the number of sellers is too small, market distortion may result. As an example of such distortions, in a statistical analysis of the "California Energy Crisis" of 2000 (where wholesale electricity prices in California reached extraordinarily high levels, resulting in considerable economic damage) Joskow and Kahn conclude in part that "…there is sufficient empirical evidence to suggest that the high observed prices reflect suppliers exercising market power"[64]. As a consequence, for grid interconnections in developing nations, it is probably more likely (and has been the pattern) that countries (or private entities) selling electricity through interconnections will be selling, at least initially, at prices negotiated with individual (state or private utility) buyers than on an open market, though markets may develop over time[65].

3. Arrangements for changing agreed prices over time

Once a set of base prices for the services to be provided via the interconnection have been agreed to, it may be necessary to also agree on a formula for the automatic adjustment of prices in response to external markets. An example here is the use of "fuel cost escalation clauses", which are formulae that specify how the price will change in response to changes in costs for the fuel used for generation or for competing fuels. The costs of gas-fired generation, for example, may change dramatically as natural gas prices rise and fall. Typically these changes in cost would be passed on to electricity consumers. Similarly, even when a fuel (such as fuel oil) is not used for electricity generation in the countries served by the interconnection, changes in that fuel's market price may be used in fuel adjustment clauses as a measure of the changing value of the electricity provided via the interconnection. Fuel adjustment clauses not only insulate power sellers from the impacts of an uncertain fuel market but also, by their nature, force the ultimate consumers of power to take the risk of fuel price changes. As such, fuel adjustment clauses do not provide an incentive for a generator to negotiate long-term contracts for fuel supply, or to make other arrangements to mitigate the impacts of the risk of future changes in fuel costs. Contracting for power supplies in general, and the setting of fuel adjustment clauses in particular, are interconnection-related activities where economic and legal issues must be addressed simultaneously.

F. CASE STUDY OF ECONOMIC COSTS AND BENEFITS OF INTERCONNECTION

An article by Enrique Crousillat includes the following summary of the estimated (future) net economic benefits of trade of electricity via an interconnection in the countries of Southeast Asia's Mekong region:

> "Recent studies comparing scenarios of electricity self-sufficiency in each country with a full trade scenario show that full trade could yield cost savings of at least US$10.4 billion in 2001–20 and a reduction of airborne pollutants valued at US$160 million a year. (These estimates assume a significant slowing in power demand over the next few years in Thailand as a result of the current [as of the late 1990s] financial crisis.) The savings would arise from:
>
> - Lower operating costs due to economic power exchange, postponed and lower investments in generation due to least-cost development of regional energy resources, and reduced spinning reserve costs.
> - Lower coincident peak load (compared with the sum of individual peak loads), mutual access to generation reserves for interconnected systems, a more robust power supply to meet such unexpected events as load growth above forecast or delayed commissioning of generation and transmission projects, and increased system reliability.

- Lower greenhouse gas emissions and other pollutants, largely due to a shift from thermal to hydro generation in the long term.”[66]

G. SUMMARY AND CONCLUSIONS

Grid interconnections may offer both direct and indirect economic and financial costs and benefits. Examples of direct economic benefits to the electricity generation systems of one or all of the nations participating in the interconnection are avoided costs, that is, direct costs that are avoided by the use of the interconnection. Avoided costs include costs for fuels used in electricity generation (and in the costs of producing those fuels), capital costs of generation facilities, operating costs of generating facilities, and capital and operating costs for any transmission facilities avoided by the interconnection. Another direct economic and financial benefit of an interconnection to a country is income from power sales, with payments for power made in hard currencies of particular importance to many developing economies. Direct costs related to the interconnection include the costs of fuels used to generate electricity for export (and of running the facilities needed to supply fuels), the capital and operating costs of generation facilities, and the costs of building and running the interconnection itself, as well as the costs of purchasing power.

The indirect costs and benefits of an interconnection can include the stimulation of national and local economies through the employment of labor needed for construction of the interconnection power line and of the power plants that will feed it and, to a lesser extent, of labor needed to operate the interconnection (and associated power plants) on an ongoing basis. Where significant amounts of short-term construction labor are needed, there is the risk of non-sustainable economic development in local areas—the “boomtown” effect. Other potential indirect economic benefits of an interconnection include the impacts of improved power supplies on fostering development of local industry, as well as improvements in education and health care. There is also the “re-spending” effect, in which an interconnection leads to a reduction in prices that households must pay for energy, leaving more disposable income available for other consumption, for savings, and for investment in productive activities. Depending on how the institution selling the power from the interconnection is configured, an interconnection may spur markets for power generation in one or more of the interconnected nations, further reducing electricity prices.

Pricing arrangements are needed to specify what the buyer(s) and seller(s) will pay and receive for electricity (electric energy and power) and electric system services (capacity and ancillary electricity system services) provided through the interconnection. Prices can be specified based on production costs or avoided costs, or through negotiation, with market-based pricing a possibility where enough buyer and sellers exist to provide for structured, fair competition. Pricing agreements between buyers and sellers, particularly in long-term sales agreements, may have fuel escalation clauses used to shield sellers from the risks of increases in generation fuel costs, and/or ensure that the price they receive for electricity will keep pace with the price of competing fuels.

Given the need for contracting and/or for market arrangements in the selling of power, the economic and financial costs and benefits of interconnections interact strongly with technical, legal, and sometimes political interconnection issues. Further, the fair distribution of economic benefits among the nations involved in an interconnection, as well as among the groups within nations that are “stakeholders” in the interconnection, is an important element in ensuring that the political and social benefits of an interconnection are maximized, and that the political and social costs are kept low. In making sure that economic benefits are fairly distributed, one key is to specify as accurately as possible what the direct costs and avoided costs of an interconnection are, preferably within the context of comprehensive long-term power system (and overall energy sector) planning. This means that analyses of the economics of power trade across all of the nations involved in an interconnection project (or set of projects) need to be a part of both short- and long-term electricity sector planning by the project participants[67].

H. RESOURCES FOR FURTHER ANALYSIS

1. Selected references on economic costs and benefits of grid integration

"Guidelines" and "Module 1" volumes of Regional Electricity Cooperation and Integration (RECI): E7 Guidelines for the pooling of resources and the interconnection of electric power systems, (Hydro-Quebec, October 2000). Prepared by the E7 Network of Expertise for the Global Environment and available as http://www.e7.org/Pages/Pu-Papers-GuidelinesRECI.html.

Wolfe, Michael, Peter Donalek and Peter Meisen. "The Economic, Environmental and Developmental Benefits of High-Voltage Interconnections between South and North America via Central America and the Caribbean." Presented at ENERLAC 93, held in Bogota, Colombia, 15-18 June 1993. Available from the Global Energy Network Institute (GENI) website as: http://www.geni.org/globalenergy/library/technical-articles/transmission/enerlac-93/economic-environmental-and-developmental-benefits/high-voltage-interconnections-between-south-and-north-america/central-america-caribbean.shtml.

World Energy Council. "Regional Electricity Trading: Issues and Challenges". Presented at the Workshop on Regional Power Trade, held in Kathmandu, Nepal, 19 March 2001. Available as http://64.224.32.197/Publications/shean.pdf.

O'Leary, Donal, Jean-Paul Charpentier, and Diane Minogue. "Promoting Regional Power Trade – The Southern African Power Pool". Public Policy Journal. Note No. 145 (June 1998). Available as http://rru.worldbank.org/PublicPolicyJournal/145olear.pdf.

2. Methods for analysis of costs and benefits of integration

Several of the integrated planning packages described in Table I.2 also include functions for evaluating the costs and market prices of electricity under different network conditions. Several summaries of other software models for computing network costs and prices under different conditions are also found at http://www.econ.cam.ac.uk/electricity/research/comparison/groups.htm, compiled by the Cambridge MIT Institute Electricity Project. Indirect benefits of electricity interconnections, the re-spending effect for example, can be quantified (roughly) using tools such as "Input-Output" models (though these are not easy to specify or run for areas where economic and employment data are difficult to obtain).

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[35] That is, the overall costs of providing electricity, and possibly even the per-unit costs of providing electric energy and power, may well rise when an interconnection is developed—especially in developing countries where the overall demand for energy services from electricity is rising fast—but the use of an interconnection allows more efficient use of resources in each of the interconnected countries, resulting in costs that are (in theory) lower than they would have been in the absence of the interconnection.

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[36] Regional Electricity Cooperation and Integration (RECI), E7 Guidelines for the pooling of resources and the interconnection of electric power systems, "Guidelines" volume, Section 5, (Hydro-Quebec, October 2000). Prepared by the E7 Network of Expertise for the Global Environment,and available as http://www.e7.org/Pages/Pu-Papers-GuidelinesRECI.html.

[37] Alessandro Clerici and Andrea Longhi, "Competitive Electricity Transmission Systems as an Alternative to Pipeline Gas Transport for Electricity Delivery", presented at the 17th World Energy Congressheld in Houston, TX, 13-18 September 1998. World Energy Council publication, available as http://www.worldenergy.org/wec-geis/publications/default/tech_papers/17th_congress/2_2_08.asp.

[38] In the more distant future, technological advances may make the use of hydrogen as an energy storage and transport medium for direct resource-to-electricity conversion methods such as hydro, solar, and wind power a large-scale reality.

[39] For example, a suggested interconnection between the Republic of Korea (ROK) and the Russian Far East (through the Democratic Peoples' Republic of Korea) might be configured for power exchanges to effectively flatten the overall load curve because the ROK system is summer-peaking, while electricity demand in the Russian Far East peaks in the winter.

[40] Regional Electricity Cooperation and Integration (RECI), E7 Guidelines for the pooling of resources and the interconnection of electric power systems, "Module 1" volume, p. 9.

[41] Margaret Matinga, "Pooling African Power: Challenges and Issues in a Reforming and Integrating Southern African Power Sector", presented at the Workshop on Monitoring Regional Integration in Southern Africa, held at Midgard Lodge, Windhoek, Namibia, 12-13 June 2004. Available as http://www.nepru.org.na/Regional%20Intergration/Power%20sector%20integration.pdf.

[42] Regional Electricity Cooperation and Integration (RECI), E7 Guidelines for the pooling of resources and the interconnection of electric power systems, "Module 1" volume, p. 8.

[43] Won-Cheol Yun, "A Strategic Approach for Electric Power Interconnection in North-East Asia", presented at the APEC Study Centre Conference Asia Pacific Economics: Multilateral vs Bilateral Relationships, held in Hong Kong, 19-21 May 2004. Available as http://fbweb.cityu.edu.hk/hkapec/Conference/Papers/Won-Cheol.pdf.

[44] See, for example, Michael Wolfe, Peter Donalek and Peter Meisen, "The Economic, Environmental and Developmental Benefits of High-Voltage Interconnections between South and North America via Central America and the Caribbean", presented at ENERLAC 93, held in Bogota, Colombia, 15-18 June 1993. Available from the Global Energy Network Institute (GENI) website as http://www.geni.org/energy/library/technical-articles/transmission/enerlac-93/economic-environmental-and-developmental-benefits/high-voltage-interconnections-between-south-and-north-america/central-america-caribbean.shtml.

[45] Francois Verneyre notes the importance of network access in "European Challenges, Overcoming Challenges", presented at the KEEI - IEA Joint Conference Northeast Asia Energy Security and Regional Cooperation, held in Seoul, Korea, 16-17 March, 2004, and available as http://www.keei.re.kr/web_keei/en_news.nsf/0/4dfb5e1e76aa3c1349256e4800150eab/$FILE/Francois%20Verneyre.pdf or as http://www.iea.org/textbase/work/2004/Seoul/Francois_Verneyre.pdf.

[46] World Energy Council, "Regional Electricity Trading: Issues and Challenges", presented at the Workshop on Regional Power Trade, held in Kathmandu, Nepal, 19 March 2001, p. 6. Available as http://64.224.32.197/Publications/shean.pdf.

[47] Regional Electricity Cooperation and Integration (RECI), E7 Guidelines for the pooling of resources and the interconnection of electric power systems, "Module 1" volume, p. 14. The source notes that DC power lines are "better" for transit distances of 1000 km or greater, but require DC-AC interconverters and other hardware that can be very expensive. The same source also presents a table showing economies of scale in power line costs (costs of power lines per unit capacity versus power line voltage), but the table is based on figures from a rather old (1985) source.

[48] Ibid, p. 28.

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[49] Michael Wolfe, Peter Donalek and Peter Meisen, op. cit., note this requirement for the "firming up of power systems" in the context of potential interconnections between the countries of Central America with North America and South America.

[50] Section IV.F.6 of this report includes a short discussion of the closely-related political issues associated with curbing illegal consumption of power.

[51] See, for example, SectionV.C.3 of this report.

[52] Additional, quite site-specific economic and other benefits may also accrue from the construction and operation of power plants built to feed electricity to the interconnection. Certain hydroelectric power plants (the Aswan High Dam in Egypt and the Akosombo Hydro Project in Ghana are cited as examples in E.A.K. Kalitsi, "Problems And Prospects for Hydropower Development in Africa," presented at the Workshop for African Energy Experts on Operationalizing the NEPAD Energy Initiative, held in Dakar, Senegal, 2 – 4 June 2003, and available as http://www.un.org/esa/sustdev/sdissues/energy/op/nepadkalitsi.pdf) may have additional benefits, including flood control, storage of water for irrigation in dry seasons or years, improving navigation, and improving fisheries.

[53] An example of the problems that can face industries dependent on uncertain electricity supplies is described in Itai Madamombe, "Energy Key To Africa's Prosperity: Challenges in West Africa's Quest for Electricity", Africa Renewal, Vol.18 #4 (January 2005), p. 6; available as http://www.un.org/ecosocdev/geninfo/afrec/vol18no4/184electric.htm. This article also describes some of the interconnection and related power projects under consideration in Africa, as well as other potential economic benefits of interconnection.

[54] See, for example, Michael Wolfe, Peter Donalek and Peter Meisen, op. cit.

[55] Vladislav Vucetic, "South Asian Regional Energy Trade: Opportunities and Challenges", presented at The World Bank/International Monetary Fund Annual Meetings, held in Washington, D.C.., October 1, 2004. Available as http://siteresources.worldbank.org/INTSOUTHASIA/Resources/Energy_a.pdf.

[56] An example of the "re-spending" effect in the context of household savings from demand-side management is described by Bruce Biewald et al., Societal Benefits of Energy Efficiency in New England, (Tellus Institute, 8 November 1995); available as http://www.cs.ntu.edu.au/homepages/jmitroy/sid101/npfdsm.html.

[57] Baltic Ring Electricity Co-operation Committee (BALTREL), Towards a Common Electricity Market in the Baltic Sea Region, (2002), p. 7. Report co-Financed by the European Commission, and available as http://www.baltrel.com/Reports/Baltrel_021202.pdf.

[58] F. Verneyre, op.cit.

[59] Robert T. Eynon, Thomas J. Leckey, and Douglas R. Hale, The Electric Transmission Network: A Multi-region Analysis (Energy Information Administration, US Department of Energy, 2002); available as http://www.eia.doe.gov/oiaf/analysispaper/transmiss.html.

[60] This discussion focuses on prices paid by utilities and others purchasing power wholesale, not on tariffs paid by retail customers.

[61] Examples of markets for ancillary services exist in a number of places, including those maintained by the PJM system in the Eastern United States (see http://www.pjm.com/markets/ancillary/ancillary.html), and the Alberta Electric Systems Operator in Western Canada (AESO; see http://www.aeso.ca/market/5137.html). For a definition of ancillary services, see Chapter I and the Glossary to this report.

[62] The costs of using alternative fuels for lighting is admittedly more reasonably compared to the costs of providing electricity for lighting from individual or village-level systems (photovoltaic, wind, or diesel systems, for example) than for the larger interconnection power source, which will likely serve a much broader array of end-uses.

[63] Donal O'Leary, Jean-Pierre Charpentier, and Diane Minogue, "Promoting Regional Power Trade – The Southern African Power Pool", Public Policy Journal, Note No. 145 (June 1998); available as http://rru.worldbank.org/Documents/PublicPolicyJournal/145olear.pdf.

[64] Paul Joskow and Edward Kahn (2002), A Quantitative Analysis of Pricing Behavior In California's Wholesale Electricity Market During Summer 2000: The Final Word. CMI Working Paper 02 (Cambridge MIT Institute,

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University of Cambridge, February 2002); available as http://stoft.com/metaPage/lib/Joskow-KahnE-2002-CA-Mrkt-Pwr-Final.pdf or as http://www.econ.cam.ac.uk/electricity/publications/wp/EP02.pdf.

[65] A summary discussion of these market options, described as “three phases of a continuum: [1] the single-buyer model, [2] the third-party or open access model; [3] the spot market or wholesale market (power pool) mode” is provided in Enrique Crousillat, “Developing International Power Markets in East Asia”, Public Policy Journal, Note No. 143 (May 1998); available as http://rru.worldbank.org/Documents/PublicPolicyJournal/143crous.pdf.

[66] Enrique Crousillat,. op.cit.

[67] An example a multi-nation economic analysis of electricity trade is described in a proposal prepared by Purdue University, in coordination with the South African Power Pool: F.T. Sparrow and William Masters Modeling Electricity Trade in Southern Africa, project proposal for funding under the USAID co-operative agreement on Equity and Growth through Economic Research/Trade Regimes and Growth (EAGER/TRADE), (Purdue University, June 1997); available as https://engineering.purdue.edu/IE/Research/PEMRG/PPDG/SAPP/1998proposal.pdf. Evaluation of the benefits of power trading should be carried out on an ongoing basis, even once grids are interconnected, to assure that the use of resources in the interconnected countries is as optimal as possible.

III. LEGAL ASPECTS OF GRID INTERCONNECTION

A. INTRODUCTION

The international flow of electric power, and of funds to pay for electricity received, must occur within a long-term legal framework that ensures trust between partners, as well as structuring straightforward and transparent dealings between the trading countries and the public and/or private institutions that support grid interconnections. A legal framework is necessary in order to identify the parties responsible for paying for power interconnection infrastructure, for the power itself, and for the costs of operating the infrastructure. In addition, and as indicated in the preceding chapter, legal agreements must specify the prices to be paid for electricity (and how those prices are to be calculated), what form of payment is acceptable, and other parameters of international funds transfer. Also, for example, legal agreements are needed to indicate which parties are responsible to any third parties harmed by interconnection-related activities, and to describe how disputes between parties are to be addressed. The legal agreements needed to establish and operate a grid interconnection both affect and are affected by the status of the legal systems within the interconnected countries—these effects can be both positive and negative.

This chapter reviews the legal issues associated with international electric grid interconnections and provides a summary of the types of institutions likely to be involved in power trading (and thus required to be involved in legal arrangements related to power trading). It describes the types of country-to-country legal agreements needed to establish and operate power lines (including legal agreements related to contractor selection), identifies some of the internal requirements needed to implement international legal agreements related to power trading (including characteristics of national legal systems that can make international legal agreements more complex) and notes some of the potential benefits to a national legal system of being involved in international agreements related to grid interconnections. In general, this chapter focuses on legal agreements between and involving national governments, though agreements with others are described to some extent as well.

B. POTENTIAL INSTITUTIONS AND GROUPS INVOLVED IN POWER TRADING

The complexity of international power grid interconnection systems (including the physical systems themselves, the institutional arrangements necessary to make them work, and the economic arrangements needed to pay for them) means that a number of very different "actors" may be involved in establishing and operating power trading arrangements. Legal agreements are needed to codify the rights and responsibilities of each of these actors relative to each other. Some of the potential "actors" (or "parties") in legal agreements related to grid interconnections, and some of the agreements that each type of party is likely to be involved in, include the following:

(a) **National governments/ministries**: National governments, usually operating through specific ministries (such as Ministries of Energy, Electricity, Infrastructure, and/or the Environment), are highly likely to be involved as parties to all but the simplest electric interconnection projections. At a minimum, governmental agencies must certify that other parties have existing rights to do business in the countries involved in the interconnections, and own or have existing rights to use the land on which interconnection facilities are built. More likely, government agencies will be responsible to some degree for energy sector planning activities that implicate grid interconnections, will be needed to provide licenses to operate for companies involved in the interconnection, will need to provide rights of access to publicly-owned land for power lines and related facilities, and will need to pledge state financial resources toward the repayment of loans—from the private sector and/or multilateral financial institutions, for example. In some cases, government ministries may be the ultimate buyers and/or sellers of electricity, obliging them to sign legal agreements to guarantee electricity supplies or consumption at a certain level;

(b) **Sub-national governments and agencies**: In many countries, the states, provinces, municipalities, or other jurisdictions that might host grid interconnection infrastructure (export-oriented power plants or power lines) may also be significant governmental actors in grid interconnection projects. The cooperation, or lack thereof, of state and local authorities can have a significant impact on decisions regarding grid interconnection projects, as the land-use, environmental, labor, and other rules at the state and local levels must be considered in formulating legal agreements that define and guide interconnection projects;

(c) **National utilities**: In many countries, national utilities, whether wholly government-controlled or semi-autonomous, are likely to own generation and transmission/distribution assets, and thus be involved in legal agreements to sell, buy, and move electricity flowing through international interconnections. Utilities, whether public or private, may also be involved in building, operating, and/or maintaining power line infrastructure, and as such will require legal arrangements that designate their rights and responsibilities as participants in the project;

(d) **Private utilities, buyers, or sellers**: Where the generation and/or transmission/distribution assets to be used in power transfers are privately-owned, private utilities will be implicated as power buyers and sellers, and may also be providers of construction, operation, and maintenance services to the power line itself. Private utilities may require different legal structures from national utilities, as they are not (directly) backed by the government. As market mechanisms in the power sector mature, privately-owned generators or electricity or bulk electricity buyers (such as large industrial enterprises or firms purchasing bulk power for distribution to an aggregated group of consumers) may also arrange, via legal contracts, to buy or sell power that will flow between countries. In some countries, the activities of private utilities (and some other electricity market actors) will be regulated, and the regulatory body will likely also either have direct responsibility for or need to be consulted in regards to grid interconnection contracts;

(e) **Private construction and/or maintenance contractors and subcontractors**: The construction of a large-volume transmission interconnection may by itself cost a billion US dollars or more, and when the major power plants needed to feed electricity into a major interconnection are included, the overall cost may be many billions of dollars. Legal contracts for construction services will need to be entered into between project sponsors (nations, private investors, and/or multilateral banks) and a firm, or likely many firms, engaged in the construction of the grid interconnection. Often, prime contractors for all or a portion of construction services will work with subcontractors, under relationships also governed by legal agreements. Similarly, the maintenance contracts for the power lines may be arranged between private companies and private or national utilities, governments, or transmission consortia;

(f) **National or multi-national transmission consortia**: In some cases, the operation of a grid interconnection may be the responsibility of a transmission consortium created for the purpose, or a consortium already operating in one of the interconnected countries. These types of consortia, which may be public, semi-public, or privately-owned, will be governed by legal agreements with the governments involved that specify their areas of operations. They will also enter legal agreements with electricity buyers and sellers to provide transmission services.

(g) **Multi-national banks and other financial institutions**: Finally, the financing for grid interconnections, and often the new power plants designed to feed them, will often come in part from multi-national development banks and/or private financial institutions (including national and international finance firms). These institutions will require contracts guaranteeing repayment from the countries and/or companies that will buy and/or sell the power flowing through the line, contracts secured by power line or generation assets, and often by general revenues from the countries involved as well.

C. COUNTRY-TO-COUNTRY LEGAL AGREEMENTS REQUIRED

The hosting of an international grid interconnection requires that the countries involved enter into a number of different types of legal agreements, often also involving some of the sub-national or multilateral/consortium parties described above.

1. Power purchase and pricing agreements

Perhaps the most obvious type of agreement that needs to be entered into between countries involved in an interconnection are agreements for selling and purchasing power, including agreements on power pricing. In power sales agreements, the seller is usually obligated to make available a certain amount of power (for example, in MW and/or GWh per year), and the buyer is usually obligated to purchase a certain amount of power. Both minimum and maximum purchases may be stipulated, or only minimums may be included in the agreement (as maximums are likely limited by the physical capacities of the line). In some cases, contracts are set up so that buyers must “take or pay”, that is, must take delivery of a certain amount of energy per year, or pay as a penalty all or part of the cost of the energy that would have been “taken” had the buyer fulfilled its obligations under the contract. Conversely, contracts often specify financial penalties to sellers that do not meet their obligations to sell power. There are generally clauses, however, in power sales contracts to address circumstances beyond the suppliers’ control that cause disruption in or curtailment of the delivery of power. Often referred to as “Force Majeure” or “uncontrollable forces,” these circumstances can include natural disasters, such as floods or droughts, epidemics and war[68]. In addition, as can be seen in the electric system interconnection agreement between the United States-based utilities CLECO Power LLC and the Southwestern Power Company[69], it would not be considered a breach of contract if a disruption of power supply were to occur due to “installation, maintenance, repair, or replacement of equipment”[70].

In some cases, power exchanges across borders are set up not so much to facilitate net sales from one country to another, but to allow countries with complementary resource endowments and/or electricity demand (such as countries with hydroelectric outputs that vary differently seasonally or over years, or countries with different seasons or times of day of peak demand) to exchange power so as to reduce capacity and reserve requirements in both countries. In these cases, power sales and purchase contracts may be structured differently.

Power pricing agreements, as noted in the previous chapter, are both legal and economic agreements. Power pricing agreements specify the price that a buyer must pay and a seller will receive for electricity. These agreements will typically have a long duration, since the power sales must pay the financing costs of the long-lived assets (power lines and power plants) that make them possible. Power prices may be fixed over time, may have a fixed escalation rate over time, may be set to escalate with one or more national or international price indices, or may be linked, in part, to international prices for other energy commodities (such as crude oil). International purchase/sales agreements will also typically specify the currency in which payments are to be made. In many developing regions, contracts may specify that payments be made in “hard” currencies, such as US Dollars or Euros, so as to insulate buyers and sellers from the impacts of local-currency inflation, as well as to provide hard-currency income for the electricity sellers. A review of the pricing arrangements and currency requirements in the Power Purchase Agreement (PPA) for the Theun-Hinboun Hydropower Project in Lao People’s Democratic Republic (Lao PDR) illustrates this point. The main goal of the project, funded in part by the Asian Development Bank (ADB), was to promote economic growth in Lao PDR by increasing the foreign exchange earnings through exporting electricity to Thailand. The completed PPA requires that 50 per cent of payments be made in Thai Baht and 50 percent in US dollars, all of which are paid to an offshore escrow account[71].

Power purchase agreements may involve parties other than the direct representatives of the trading nations, including national or private utilities, transmission consortia or, in countries where electric sector restructuring is relatively advanced, private suppliers and/or buyers of power. The nature of the electricity buyer and seller in interconnection arrangements has a strong bearing on both the prices ultimately paid for power and how pricing arrangements are reached. For example, as noted by Neuhoff, in the case where integrated monopolies are the actors on both the importing and exporting side, rather than a negotiated market price for electricity,

> “The price for the electricity will be between the costs of the exporting country and the costs of the outside option for the importing country. If long-term contracts are to be signed the outside option of the importing country is to construct new power plants. If short term prices are negotiated the outside option for the importing country can be anything between running inefficient diesel generators and cutting power supply to part of the demand side. If power trade is based on commercial interests and the exporting country has no competitive market and the import country has no short-term substitute for electricity imports then long term contracts are vital for the importing country.”[72]

In most international power purchase agreements to date, nations are typically the ultimate legal guarantors of purchases or sales. The Lao PDR Theun-Hinboun Hydropower Project mentioned above, and the Bujagali Hydro Project in Uganda, are examples here. In both cases the respective governments borrowed funds, in part from the Asian Development Bank in the former case and from the African Development Bank, the World Bank and the International Finance Corporation (IFC) in the latter case, to finance the majority of the costs of the projects. In the PPA of the Bujagali project, signed in November of 1999, the government guarantees all payments that are to be made by the Uganda Electricity Board (UEB.) If UEB should default on any payments, the government will immediately cover the costs. Therefore, although there is private sector involvement in both of these interconnection cases, the governments are the legal guarantors of the loan repayments[73].

2. Agreements on siting of power line and related infrastructure

In addition to agreements on the quantities of power to be transferred, and the prices to be paid for power, in virtually all circumstances where power lines cross national borders the nations involved must agree on the siting of power lines and related infrastructure, such as substations and control centers. Governments must agree to provide a right-of-way for the power line through publicly-owned land, and must work with private landowners to secure additional land or easement rights to traverse private land. Frequently, siting power lines will involve a process of negotiation between governments to determine which routing is “best” from the perspectives of each country and of the interconnection as a whole, and will also involve negotiations with sub-national groups representing the populations in areas where power lines will pass.

3. Agreements on operation of power line

In power purchase agreements or subsidiary agreements, the interconnected countries must agree on what entity will operate the power line, and how the governments will work with that entity (whether it is a public or private utility, a consortia of utilities and/or other public or private agencies, or a new entity created to run the line) to make sure that the power line operates smoothly and with adequate input from the parties to the power purchase agreements. Agreements will also be needed to specify the rights of generators and power consumers to, and costs to be paid for, transmission access (“wheeling”) services. Legal agreements must also specify what “remedies”—opportunities to address problems—the parties to the agreement (the electricity buyer, the seller, and others) will have if there is a disagreement over how the power line is operated. For example, the legal agreement may specify that the power line operator, while responsible for day-to-day decisions related to the operation of the line also is subject to the oversight of a “board of directors”, “transmission commission”, or some such authority made up of members appointed from each of the countries involved in the interconnection. Such an authority would ideally be composed of members from different interest groups within their nation, including utilities, government, business, and civil society[74]. An agreement specifying the responsibilities of the power line operator, the authority of the operator over other parties in the interconnection, and the authority of the parties, through an overseeing body, over the operator, would typically be part of any electric grid interconnection where the operation of the interconnection has a significant impact on the operation of the national grids that it connects.

As a part of power line operation, agreements will be needed as to which entity (for example, utilities, governmental ministries, and/or the transmission operator) will be responsible for maintaining the power line right-of-way in each country through which it passes. This will mean, for example, designating which organization will be responsible for making sure that vegetation in the right-of-way does not impede power line performance or present a fire hazard, as well as making sure that safety and environmental regulations (see below) with regard to power line operation are agreed upon.

4. Agreements on power line security

An electricity transmission interconnection that is relied upon to provide a significant amount of income to a national grid and/or to provide significant hard-currency income must be secured from attack or other damage. Here “attack” in most instances will probably mean malicious damage to the power line caused by sub-national groups unhappy with national government decisions (including, but certainly not limited to, decisions related to the power line itself). Power lines can also be damaged by thieves trying to illegally tap power lines to obtain "free" electricity, or looters looking to sell power line components (such as metals in towers and conductors). Agreements between countries participating in the interconnection will be needed to set out responsibilities for maintaining the security of the power line in the territory of each nation through which it passes, and to specify damages to be paid (and responsibility for repair of the line) if there are breaches in security.

5. Agreements on interconnection environmental performance

The construction and operation of power lines are typically subject to a variety of national environmental and safety regulations. These regulations include, for example, the width of the transmission rights-of-way for lines of a given voltage and capacity, the required height of conductors above the ground and transportation crossings and their distance from surrounding vegetation, the distance that power lines must maintain from human dwellings, and the strengths of electric and magnetic fields at specific distances from the lines. Regulations may also specify how construction of power lines must be managed to minimize environmental degradation, including mitigating impacts on vegetation, wildlife, and land use by indigenous populations. It may be necessary for countries sharing a power line to have their legal agreements for the construction and operation of the interconnection project include aspects such as the harmonization of safety, environmental, and other regulations in the trading countries. In some cases this harmonization may be driven by the requirements of multilateral lenders or other financing organizations[75].

The need for the harmonization of relevant environmental standards between the countries participating in the interconnection was noted in the context of the Baltic Ring interconnection project in Northern Europe, and deemed "…a challenging task, due to the difference in power generation portfolios, economic and political situation, as well as other framework conditions" [76]. It was noted that there is a need for the interconnection consortium (in this case the BALTREL organization) to play an intermediary role in helping the harmonization process.

6. Agreements on liability for power line failure or damage, and other issues of legal liability concerning grid operation

Agreements between nations, and between other parties involved in building and operating an interconnection project, will also require legal designations of liability for problems of different types. For example, vendors and/or installers of transmission equipment may be held liable for technical failure of transmission infrastructure up to a certain date. Construction and other contractors would typically be required to carry insurance to compensate any party who could prove they were injured by the power line. Beyond these considerations, however, nations may be required to agree on who is responsible, and who is not, for damages caused by the power line operation, or by its failure. These damages could include failure of appliances or commercial or industrial equipment caused by voltage spikes or frequency fluctuations, or claimed damages by businesses unable to operate due to power outages (or poor power quality) traceable to the operation of the interconnection.

D. LEGAL AGREEMENTS AND PROTOCOLS FOR SELECTION OF INTERCONNECTION PROJECTS AND OF CONTRACTORS FOR POWER LINE CONSTRUCTION

A specific group of legal agreements not covered in the listing above are agreements as to how grid interconnection projects are selected, where several options exist, and how contractors and subcontractors for power line construction (and sometimes operation) are to be selected. These agreements would typically be signed by the nations involved in the interconnection, and will likely often be strongly influenced by the requirements of the organizations providing project financing. In countries where graft is consistently a problem, the clear designation and implementation of an impartial protocol for selecting one potential project over another, and for selecting, overseeing, and paying construction and other contractors, can be a significant measure to boost confidence between the countries.

1. Protocols to ensure transparency in the selection and evaluation of grid interconnection prospects

For any given proposed interconnection between neighboring grids there may be several distinct possible "projects" among which the parties to the interconnection must choose. A grid interconnection, for example, may be used to transport power generated at one or more of several different proposed power plants, over one or more of several proposed routes to one or more points on the receiving grid. Each option may well have its own set of specific beneficiaries and groups who are negatively affected—its own set of "winners" and "losers". As such, it is important that the countries participating in the proposed interconnection decide and codify early in the process a systematic, clear, and legally-based means of selecting among major project options. This process would include ensuring transparency between the countries partnering to trade power (for example, through an exchange of technical information on national power demand, power systems, power development plans, and environmental data) so that the interconnection option chosen could be ensured, as much as possible, to be a "best fit" to the needs of all interconnected nations[77]. The process would also include transparency in terms of public information and participation in the project design process—meaning making all (or most) documents related to the discussion available for review by the public in general or by suitably accredited representatives of a wide variety of groups from the citizenry of all of the interconnected nations (and others, such as upstream and downstream countries potentially affected by hydroelectric development). These two issues may also be pre-specified to a degree by the requirements of multilateral financial institutions, if the latter are involved in financing. Ensuring that parties to the interconnection adhere strictly to legal protocols for information provision and for inclusion of all relevant groups is likely to prevent, or at least reduce, legal, political, social, and economic problems as the project is developed.

2. Protocols and requirements for selection of contractors

Many nations, both industrialized and developing, can be justifiably accused of having shown favoritism in the awarding of lucrative infrastructure design and/or construction contracts at various times in the past (if not the present). Such favoritism, at a minimum, leaves other potential contractors disaffected by the selection process, and has the potential to create lingering resentment between the partner nations. More extreme potential results of an unfair contracting process can include wasted financial resources, shoddy workmanship by unqualified contractors (putting the project technically and/or environmentally at risk), and even the risk that the project will not be finished at all (among many other potentially negative outcomes). To guard against the possibility of graft in contractor selection, participating nations should agree beforehand to a systematic, impartial contractor selection process overseen by a broad group of representatives from participating and affected parties in all of the nations involved in the project. This would include broad, public dissemination of calls for proposals, clear listings of the criteria by which competing proposals will be judged, clear and unbiased definition of contracting requirements, the definition of a transparent system for judging of proposals, and the public announcement of winning bids. For large projects, legal agreements between countries may also include requirements for the process with which contractors select local (or international) subcontracting firms, again to ensure that such selections are carried out in a manner that gives competing firms a fair chance and assures project participants (countries, financial institutions, and ultimately, electricity ratepayers) that their funds are being used wisely.

The same types of criteria for avoiding favoritism and graft in the selection of design and construction contractors also may apply to the selection of organizations that will provide project financing or will operate the interconnection[78].

3. Institutional arrangements for governing grid interconnections

In addition to the types of legal arrangements needed for the day-to-day operation of a transmission interconnection (as noted in section C.3 of this chapter), legal agreements may be needed to specify how overall governance of transmission facilities connecting the power grids of two or more nations will be accomplished. The governance structure for an interconnection ideally should be in place, or at least agreed to, as planning for the interconnection begins, so that all parties understand their legal responsibilities as project planning, construction, and operation go forward. The governance structure for the project could include, for example, a professional Executive Director reporting to a board of representatives from all participating countries, and representing a diverse set of interest groups. Here again, clarity in the organization of the governance structure, and of the legal rights and responsibilities of each participant in the structure, is crucial to project success and to minimizing conflict as the project develops. These types of governance arrangements, clearly set forth in such a way as to give legal standing to the partners in the interconnection, are essential for securing international financing[79].

4. Case study of legal and treaty arrangements for grid project development: the Southern African Power Pool

The Southern African Power Pool (SAPP), formed in 1995, was the first formal international electricity generation pool established outside of Europe and North America. The SAPP was established to increase the level of electric grid interconnections in southern Africa, with the goal of reducing energy costs and creating greater supply stability in the region. Accordingly, “the purpose of the pool is to allow its members to coordinate the planning and operation of their systems while maintaining reliability, autonomy, and self-sufficiency, and to share in the benefits of operating the pool.”[80] The membership of SAPP consists of the national power utility companies of the twelve southern African countries including: Angola, Botswana, Democratic Republic of Congo (DRC), Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe.

Regional energy disparities, coupled with the diverse range of power sources found in certain areas of southern Africa, led to the exchange of power in the region. Ample low-cost hydroelectricity in the north, predominantly coming from the Inga system in DRC and the Cahora-Bassa reservoir in Mozambique, and large quantities of affordable coal-fired power in South Africa supply much of the electricity traded in the SAPP. Similar to the NORDEL/NordPool, the power pool in Scandinavia, the Southern African Power Pool was originally established as a "loose pool", with regional power cooperation being the main goal. Starting in the early 2000's it began moving towards a more competitive pool structure. The amount of electricity traded each year through the Pool continues to increase substantially[81].

The SAPP is based on a set of agreements as opposed to formal laws. The Inter-Governmental Memorandum of Understanding (MOU), signed on 28 August 1995, and its subsidiary agreements (the Inter-Utility Memorandum of Understanding, the Agreement Between Operating Members, and the Operating Agreement) outline the basic operating conditions of the pool. In December 1995, the Inter-Utility Memorandum of Understanding was signed by the national power utilities of member countries to establish the specific rules and procedures upon which the SAPP would operate. The Inter-Governmental MOU states that the SAPP agreements and operating conditions must be in accordance with the SADC (Southern African Development Community) treaty, and that disputes among operating members will be settled in the SADC Dispute Resolution Tribunal. Furthermore, the energy ministries of SADC countries are the responsible parties for admitting new members into SAPP, and for resolving major policy issues of the pool[82].

As outlined in the current MOU, full membership of SAPP is limited to the national utilities of member countries, which are designated by the government of that country. There are two types of members: Operating members and Non-Operating members. The operating members are signatories of all the pertinent agreements listed above, are required to operate in accordance with all procedures and guidelines as outlined in SAPP, and must be internationally connected to at least one other operating member. Non-operating members are those who have only signed the Inter-Utility Memorandum of Understanding. These members participate in all activities of the pool with the exception of those related to the operation of the pool. An executive committee, functioning as the board of directors, is the organizational body of the SAPP, while a management committee, broken down into three sub-committees (planning, operating, and environmental) overseas the administration of the pool.

The diverse and complimentary power sources of this region of Africa, the presence of a strong regional cooperation for economic development and stability, and the political will to increase regional electricity trade of the southern African countries have been three of the most important factors in determining the success of the Southern African Power Pool.

E. NATIONAL REQUIREMENTS FOR LEGAL AGREEMENTS TO BE PUT IN PLACE

In order for nations to reliably participate in the types of legal agreements identified above, as well as meaningfully participate in the negotiation and drafting of those agreements, a domestic legal structure is an important prerequisite. Although countries lacking a strong "rule of law" structure may be able to participate successfully in grid interconnection projects, countries with existing frameworks for contract enforcement, significant human capacity in the legal and judicial professions, effective and consistent regulatory structures, stable political systems, and experience in being a party to international legal agreements will have a smoother path to success in interconnection projects.

1. Effective existing legal framework

A key to smooth negotiation and enforcement of contracts related to international electric grid interconnections is the existence of an effective legal framework for contract enforcement in each of the countries participating in the interconnection. The existence of an independent, experienced judiciary with (at least typically) predictable paths for registering and pursuing legal complaints allows contractors to proceed with a greater degree of confidence in agreeing to undertake activities related to interconnection construction or operation. Reliable and independent national judiciaries also give trading partners confidence that their grievances related to the interconnection (if any) will be fairly addressed. The existence of reliable and independent national judiciaries also allow contracts related to the interconnection to be formulated so as to indicate clear national jurisdictions over the different types of disputes that may occur during interconnection contracting, construction, and operation.

2. Professional legal capacity

The availability of adequate professional legal capacity in each of the countries goes hand-in-hand with an effective existing legal framework as a prerequisite for a smoother process of negotiation and enforcement of legal contracts between the parties to an interconnection. This means having groups of lawyers in each country who are sufficiently well-versed in their own nations' laws and in international contract law to actively review and comment on draft contracts related to interconnections, or at least to oversee teams of outside lawyers engaged from outside for the purpose. Ideally, lawyers from each nation should have experience and training in contract law related to energy transactions. Similarly, the existence of a set of judges in each country who are reliably familiar with adjudicating contract disputes, and ideally also familiar with dealing with international contract disputes, is likely to make the process of resolving any disputes related to the interconnection much easier. It is recognized that experienced legal and judicial capacity, and especially lawyers and judges with experience in energy sales contract litigation, will be difficult to find in many developing countries that are potential partners in grid interconnections. As a consequence, professional legal training courses that build such capacities may be an effective early step in the exploration of interconnection opportunities.

3. Professional financial services capacity

Along with the need for legal capacity to create and enforce contracts is the need for financial sector capacity to service those contracts. This means ensuring that national and regional banking systems are available and reliably up to the task of handling funds to pay contracts for construction and operation as needed, and other tasks to generally ensure the timely, smooth, and efficient flow of financial resources related to an interconnection. Other financial services, such as insurance and performance guarantee instruments, will also be required in interconnection projects. In some countries, "gearing up" (preparing) to provide the legal services necessary to support an interconnection project will also involve building or reinforcing capabilities in the financial services sector[83].

4. Effective and consistent regulatory systems

The capacity for regulation of utilities, particularly non-government-owned utilities, is related to professional legal capacity, though (usually) not part of the legal sector strictly speaking. When the countries participating in interconnections have regulatory structures in place and functioning, and particularly when those regulatory entities share common structures and/or membership in common organizations (such as southern Africa's Regional Electricity Regulators Association--RERA and the African Forum of Utility Regulators--AFUR) the specification of the regulatory requirements that must be met by organizations participating in interconnections may be simplified[84]. The existence of consistent, independent regulatory authorities helps to insure participants in interconnections against arbitrary changes in tariffs or other rules affecting their business[85].

5. Stability of government and impact on legal obligations

The stability of national governments is one of the political issues that can strongly affect the feasibility of grid interconnections between nations, and is treated as such in Chapter IV of this report, but governmental stability can have legal implications for interconnections as well. Partners in potential interconnection projects need to be able to be assured that the agreements that are signed between nations will be honored by succeeding governments. This does not necessarily mean that an individual government's administration needs to be long-lived, but it does mean that countries with a clear and orderly means of government succession, a judicial system that is independent of the administration in power, a pattern of retaining sub-ministerial level officials (who are likely to be involved in administering grid interconnections), and above all, a tradition of honoring contracts agreed to by previous office-holders, will make the best partners for international grid interconnections.

6. Agreements for appeal to international courts

Some aspects of contracts between countries in interconnection projects may call for appeals to international courts. If the national parties involved in the interconnection have a history of abiding by the decisions of international courts, particularly in issues related to trade, some aspects of interconnection contracts having to do with resolution of disputes between countries may be more easily dealt with by agreements to refer such matters to international jurisdictions.

A paper from the Workshop on Regional Power Trade (held in Kathmandu, Nepal, in March 2001) makes the following point about the importance of the dispute resolution process:

> "The dispute resolution process is an important element of governance [of grid interconnections]. In this context transparency may take on a slightly different meaning. Dispute resolution between private interests in different countries may be transparent to those parties but not be perceived as being transparent, or in the interest of the general public and government policy. For example, private interests who are operating under the North American Free Trade Agreement submit any disputes to one of two tribunals: the International Center for Settlement of Investment Disputes started by the World Bank or the United Nations Commission on International Trade Law. The workings of these tribunals are confidential to the disputing parties. While that may be appropriate for disputes between private parties, when the dispute involves public bodies the issue of openness and public accountability is raised. Disputes arising from regional electricity trading may transcend the purely technical or administrative issues involved in regional trading and encompass broader matters of social concern and public policy. Safeguards should be considered by the countries involved in regional trading to protect the public's interest." [86]

F. POTENTIAL LEGAL COMPLICATIONS

The legal contracting requirements for a project as complex as a grid interconnection, as indicated in the preceding part of this chapter, are often more than substantial. These requirements become even more complex when contracts must link the activities within countries that may not only have different legal systems and traditions, but even different languages. The ongoing process of electricity sector restructuring (which is often in radically different phases in different countries) further complicates the negotiation and implementation of legal agreements related to grid interconnections.

1. Contracting between countries with different legal systems

Complications can arise when contracts related to construction and operation of grid interconnections must be written that involve countries with different legal systems and traditions. Countries with relatively independent judiciaries, for example, may not be comfortable trusting the courts in a neighboring country where the judiciary is known to be politically controlled. Further complications can arise where a partner in an interconnection project follows religious as well as secular law. Agreement must also be made concerning the language (or languages) of contract documents, and where several languages are used, a procedure is needed to ensure that all translations of legal documents are functionally identical.

2. The impacts of privatization or restructuring

Recent trends in the worldwide utility industry toward private ownership and operation of generating resources, and/or toward restructuring of traditionally vertically integrated state utilities, may in some instances further complicate the legal aspects of setting up and operating grid interconnection arrangements between countries. In some of the countries that are contemplating international electric grid interconnection projects today, the state-run utility electric service providers that would be key parties to the legal agreements to buy or sell power may effectively cease to exist within 10 years—which would be well within the life of the interconnection infrastructure.

Within the next decade, many nations may have transformed their state-run monopoly utilities into partially or totally market-oriented electricity buyers, sellers, and transmission companies—with market regulation structures that may be strong or weak. Who, at that point, would be the buyer and/or seller of electricity from or to the international interconnection? As it is impractical, to say the least, to set up legal arrangements between businesses that do not yet exist, this means that the individuals and groups that draft interconnection agreements must keep in mind the changing structure of the electricity sector in the countries as they prepare contracts to buy and sell power. One possibility is that designated buying or selling organizations that are and, by contract, will continue to be state-run will be the primary buyers and sellers of power, and can then sell the power on to (or buy power from) buyers and sellers operating within a market structure at the national level. Another possibility, once grid interconnections between countries reach high levels, is that power from interconnections is sold and purchased through regional power markets, which require a whole different set of agreements, and possibly different financing arrangements as well. Given the possibility/probability that electricity sector actors that are parties to power sales and purchase contracts may well find their roles changing dramatically in the coming years, it may be prudent for interconnection contracts to include clauses allowing negotiations to be re-opened in the event of electricity sector restructuring, although such clauses may imply risks for project sponsors.

Conversely, once the electricity markets of one or more potential trading partners *are* restructured, the (presumably liberalized and clearly defined) markets that are created may help to clarify the potential role of power imports and exports in the electric system, providing a clearer path to the pricing of traded energy, and thereby reducing the risk of investing in power grid interconnections.

3. Existing contracts

In some countries, existing long-term contracts between electricity suppliers and wholesale consumers (such as distribution utilities) may act as legal impediments to grid interconnections by mandating certain levels of supply from specific sources. These existing long-term contracts, depending on how they are structured, may effectively prevent (or dramatically increase the financial risk of) some of the potential partners in an interconnection from entering into additional agreements to buy or sell power.

G. POTENTIAL BENEFITS TO NATIONAL LEGAL SYSTEMS

Complex as they may be, the experience of preparing and complying with the legal agreements required in setting up grid interconnections offer several potential benefits to national legal systems. These benefits include the building of national professional legal capacity through the experience of negotiating, reviewing and, as necessary, litigating interconnection contracts, but also the benefits of setting a precedent for legal standards in cross-border trades, and also of demonstrating national reliability in adhering to international contracts.

1. Establishing cross-border legal standards

Completed, accepted, and successful agreements to share power resources between nations can serve as templates for other types of cross-border legal agreements. Other types of agreements between neighboring countries could include agreements to buy and sell other energy resources, minerals, or other natural resources, agreements to jointly build, maintain, and operate international transportation networks[87], agreements on conserving environmental resources (including water) that cross national borders, agreements related to greenhouse gas emissions trading, or even agreements on sharing labor resources. Once the required legal transparency for settling interconnection issues has been developed, the experience may help the implementation of needed reforms in other areas of the national legal system, leading ultimately to a more open and trustworthy (both for outside and domestic parties) national legal process.

2. Building confidence of outside parties in the national legal system

In addition to the implications of legal agreements related to interconnection for the national legal system, the demonstrated adherence by a country to an international contract (the interconnection agreement) may help to increase the confidence of outside parties in the country's national legal system. When a country, particularly a country that has previously had a record of difficulty in abiding by contracts with external parties, demonstrates its trustworthiness in making the contracted payments and providing the contracted energy covered by the interconnection agreement, outside confidence in the country's ability to follow through on legal obligations is enhanced. In a related manner, when legal proceedings related to the interconnection contract take place in a national court and proceed in a smooth, orderly and demonstrably fair fashion, one consequence is likely to be higher confidence of foreigners in the national legal system, thus lowering potential barriers to increased trade between countries.

H. SUMMARY AND CONCLUSIONS

International electric grid interconnections, except perhaps in their very simplest forms, can be very complex legal undertakings, involving a variety of national, sub-national, and even international parties to the agreements required for planning, building, and operating power lines used to buy and sell electricity across borders. As such, binding legal agreements between countries (and between the countries and the outside lenders, if any, providing project financing), as well as the negotiation processes that produce the agreements, must be transparent and enforceable. This requires national legal capacity to draft, review, enforce, adhere to, and in the event of a disagreement, adjudicate contract issues.

A past history of having an unpredictable or corrupt legal system, or a legal system that changes markedly when governments change, may prove a detriment in negotiating power trading deals, whereas, conversely, a nation's history of adherence to the Rule of Law at a high international standard may smooth the path to power-sharing agreements. The existence of interconnection agreements can help to pave the way for agreements between nations on other important matters, including trade in other resources, and other joint projects. The experience gained in negotiating and complying with the international agreements required to build and operate an interconnection can also serve to build confidence in a country's legal system and to provide a source of experience in international-standard legal system operations.

Some of the key issues, as discussed above, that must be addressed when setting up a legal framework for international electric grid interconnections include:

(a) *Power purchase and pricing* agreements, including agreements on the currency of payment, the escalation and/or indexing of prices to prices of other energy commodities over time, and penalties if sales or purchase minimums are not met;

(b) Agreements on *siting of power lines* and related infrastructure, such as routes between generating plants and consuming grids, and placement of substations and interconverter (for AC-DC-AC systems) stations;

(c) Agreements on *power line operation*, including deciding upon or constituting a joint authority to operate the interconnection, and agreeing on how the power line operator will be governed or overseen by both parties. Agreements on power line operation will also include agreements on how the interconnection right-of-way is to be maintained;

(d) Agreements on *power line security*, including agreements on which parties will be liable in the event of different types of incidents resulting in power line damage;

(e) Agreements on the *environmental performance* of the interconnection, potentially including environmental standards to be met during construction of the line, and environmental and safety (including fire safety) standards to be met during line operation;

(f) Agreements on *liability for power line failure*, including damages to third parties caused by power line failure;

(g) Agreements for the orderly, fair, and open *selection of contractors* to build and/or operate and maintain interconnection infrastructure, including agreements on how such contractors are to be overseen by parties to the project.

I. RESOURCES FOR FURTHER ANALYSIS

1. References on legal requirements

"Module 6: Financing Interconnection Facilities" volume of Regional Electricity Cooperation and Integration (RECI), E7 Guidelines for the pooling of resources and the interconnection of electric power systems, (Hydro-Quebec, October 2000); prepared by the E7 Network of Expertise for the Global Environment and available as http://www.e7.org/Pages?Pu-Papers-GuidelinesRECI.html.

World Energy Council. "Regional Electricity Trading: Issues and Challenges". Presented at the Workshop on Regional Power Trade, held in Kathmandu, Nepal, 19 March 2001. Available as http://64.224.32.197/Publications/shean.pdf.

2. References from multilateral institutions

The World Bank web page "Procurement: Information for Borrowers" includes access to a number of documents that provide guidance and training in Bank-approved and Bank-required processes for procurement and for the hiring of consultants for countries using Bank loan funds. See http://web.worldbank.org/WBSITE/EXTERNAL/PROJECTS/PROCUREMENT/0,,contentMDK:20064677~menuPK:84283~pagePK:84269~piPK:60001558~theSitePK:84266,00.html.

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[68] The following is a more comprehensive list of the circumstances that can be included under the category of Force Majeure: sabotage, strikes or other labor difficulties, riots, civil disturbances, acts of God, acts of public enemies, drought, earthquake, flood, fire, explosion, lightening, landslides, or similar cataclysmic events, or appropriation, diversion, or interruption of service by any court or government body having jurisdiction over such agreements.

[69] Information for this section was obtained from the Electric Power System Interconnection Agreement between CLECO Power LLC and the Southwestern Power Company, November 2001, available as http://www.cleco.com/uploads/RS17.pdf, and the Unit Power Sales Agreement among Southwestern Electric Power Company American Electric Power Service Corporation, July 2001, available as http://www.aep.com/newsroom/resources/corpsep/docs/ATT4.pdf.

[70] Electric Power System Interconnection Agreement between CLECO Power LLC and the Southwestern Power Company, November 2001, section 5.15, p 11, available as http://www.cleco.com/uploads/RS17.pdf.

[71] Information obtained from the following sources: The Theun-Hinboun Hydropower - Project Profile, Asia Development Bank (ADB), initial profile dated November 1998, available as http://www.adb.org/Projects/TheunHinboun/, and Robert Kay, "Impact of the Financial Crisis of the Energy Sector: a Developer's Perspective", presented at Energy Week 1999: The Global Shakeout (The World Bank Group), available as http://iris37.worldbank.org/domdoc/PRD/Other/PRDDContainer.nsf/ALL+Documents/85256D2400766cc7852570060052D26D/$FILE/kay_pres.pdf.

[72] Karsten Neuhoff, "Economic Considerations for International Electricity Interconnections in North-East Asia", presented at the Workshop on Power Grid Interconnection in Northeast Asia, held in Beijing, China, May 14-16, 2001, and available as http://www.nautilus.org/archives/energy/grid/papers/neuhoff.pdf.

[73] Information obtained from the following sources: The Theun-Hinboun Hydropower - Project Profile, Asia Development Bank (ADB), March 3, 2005; http://www.adb.org/Projects/TheunHinboun/; and The Bujagli Power Purchase Agreement – an Independent Review, by Prayas Energy Group for International Rivers Network, November 2002, http://www.enteruganda.com/uploaded_files/Bujagali%20PPA%20Review.pdf. The independent review in the latter document found (in summary) "The Power Purchase Agreement of the private project is not in line with international standards, and entails massive extra costs for Uganda." This particular Power Purchase Agreement should therefore be considered with great care before it is used as a model in any way.

[74] For example, the transmission authority for the Australian state of New South Wales, know as Transgrid, is governed by a board of directors that includes a Labour Council representative. See http://www.tg.nsw.gov.au/about_us/profile.html.

[75] In some instances, including environmental regulations related to construction, for example, it may be possible to maintain different standards on the different sides of the border or borders spanned by the interconnection (though it is probably easier for construction contractors to comply with a single set of standards throughout the project). In

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other instances, environmental or safety regulations may absolutely need to be harmonized for the project in order to, for example, be able to choose what types of towers and conductors will be used to meet safety and electromagnetic field strength standards.

[76] Baltic Ring Electricity Co-operation Committee (BALTREL, 2002), Towards a Common Electricity Market in the Baltic Sea Region, p.7. Report co-Financed by the European Commission, and available as http://www.baltrel.com/Reports/Baltrel_021202.pdf.

[77] This requirement for sharing information is described under the heading "Exchanging information on the development and operation of power systems" in Section 1 of the "Guidelines" volume of Regional Electricity Cooperation and Integration (RECI), op.cit.

[78] Notes on procedures for properly securing and evaluating bids on financing and operation of interconnections can be found in the "Module 6: Financing Interconnection Facilities" volume of Regional Electricity Cooperation and Integration (RECI), op.cit.

[79] Some of the types of agreements needed to formalize the institutional structure of an interconnection, as well as some of the steps involved in reaching those agreements, are described in Chapter VI of "Module 6: Financing Interconnection Facilities" volume of Regional Electricity Cooperation and Integration (RECI),op.cit.

[80] Donal O'Leary, Jean-Pierre Charpentier, and Diane Minogue, "Promoting Regional Power Trade – The Southern African Power Pool", Public Policy Journal, Note No. 145 (June 1998), available as http://rru.worldbank.org/Documents/PublicPolicyJournal/145olear.pdf.

[81] Southern African Power Pool (SAPP), (Energy Information Agency, U.S. Department of Energy, November 2002), available as http://www.eia.doe.gov/emeu/cabs/sapp.html.

[82] SAPP Operating Sub-Committee, "Energy Trading in the SAPP", ESI Africa, No. 1 (2003); available as http://www.esi-africa.com/last/ESI_1_2003/031_36.htm.

[83] Vladislav Vucetic, "World Bank's South Asia Energy Program", presented at the USAID SARI/Energy Semi Annual Meeting, held in New Delhi, October 12-13, available as http://sari-energy.org/PPTdisplay.asp?PresentationID=PPT103Oct04.

[84] Margaret Matinga, "Pooling African Power: Challenges and Issues in a Reforming and Integrating Southern African Power Sector", presented at the Workshop on Monitoring Regional Integration in Southern Africa, held at Midgard Lodge, Windhoek, Namibia, 12-13 June 2004, and available as http://www.nepru.org.na/Regional%20Intergration/Power%20sector%20integration.pdf.

[85] Enrique Crousillat, "Developing International Power Markets in East Asia", Public Policy Journal, Note no. 143,(May 1998), available as http://rru.worldbank.org/Documents/PublicPolicyJournal/143crous.pdf.

[86] World Energy Council, "Regional Electricity Trading: Issues and Challenges", presented at the Workshop on Regional Power Trade, held in Kathmandu, Nepal, 19March 2001., p. 6. Available as http://64.224.32.197/Publications/shean.pdf.

[87] Often the least environmentally and socially-disruptive areas to build electricity transmission lines are in existing transport corridors, such as along roads and railroads. Similarly, transmission corridors may serve as hosts for transport links between countries.

IV. POLITICAL ASPECTS OF GRID INTERCONNECTION

A. INTRODUCTION

An effective international legal framework governing the construction and operation of any international electric grid interconnection requires political agreement and cooperation between the trading countries, as well as between different constituencies inside each of the trading countries. At the same time, the presence and operation of an international power line can provide both political benefits, ranging from enhanced potential for international cooperation to increased democratization at home, and liabilities, ranging from dependency on another country to internal squabbles over power line benefits. This chapter reviews some of the key potential political benefits and liabilities of international grid interconnections, describes the types of political cooperation required between and within countries to make grid interconnections work effectively, and notes national attributes that favor successful interconnections. Here political benefits and liabilities are defined as those impacts that enhance or degrade the political relationships between countries, or between different constituent groups within countries. This chapter also includes discussions of the potential political barriers to grid interconnections that may be encountered and suggests approaches through which those barriers might be overcome.

B. POTENTIAL POLITICAL BENEFITS OF INTERNATIONAL GRID INTERCONNECTION

International power grid interconnections can offer political benefits to the countries participating in power trading, as well as to individuals and groups within the trading countries. Making sure that political benefits are wisely distributed and used should be a focus in planning for interconnection projects. The potential benefits of interconnections for international cooperation, in providing incentives for conflict avoidance, in spurring democratization, and in promoting political stability are discussed below.

1. International grid interconnection as a spur to additional international cooperation

The significant legal, economic, and organizational linkages between nations trading power, which are obligatory parts of most successful grid interconnections, offer the potential to spur government-to-government cooperation in other areas. A grid interconnection necessarily sets up means of communication between governments in that, as noted in the previous chapter, representatives of the governments involved in the interconnections must agree on the terms of power sales and purchase agreements and must cooperate in the operation of shared power lines. The international political and legal frameworks necessary to build and operate major international energy infrastructure such as power lines (and, for example, gas or oil pipelines) provide experience and channels for international communication on economic (such as trade in other goods and services), social (such as indigenous peoples and cultural exchanges), and security (such as border control) issues, to name just a few. This spur to additional cooperation can be particularly important if the countries linked by the interconnection have had a history of conflict, as do many neighboring nations in Africa, Asia, and in other regions.

2. Presence of power interconnection as a force for avoidance of conflict

Resource sharing, and the mutual dependence that it implies, provides an incentive for the partners in the sharing arrangement to work out any disagreements through non-military means, thus improving security. By tying the economy to that of its neighbors, the sharing of a very expensive and valuable asset (the interconnection line itself) arguably improves energy security by reducing the likelihood of military action against each other by the nations involved in power trading. Such actions would, if resource sharing arrangements were in place, result in harm to the economies of all of the interconnected nations, not just the nation initiating the conflict. Further, if more than two countries are involved in the interconnection, each party has an incentive to ensure that differences between other parties are settled amicably, without conflicts that could interrupt the operation of the interconnection. The flows of power, and of the money (often hard currency) that pays for the power, provide a strong financial and practical incentive for the countries trading electricity to work out their differences on other matters peacefully, as well as providing an example of how such agreements can be reached.

3. Grid Interconnections may help to encourage democratization

Depending on how a grid interconnection project is developed, decided upon, and managed, grid interconnections have the potential to encourage democratization. As noted in Chapter III, a number of legal agreements must be set and adhered to in order to ensure the smooth operation of an international grid interconnection. If the process of planning a grid interconnection proceeds in a transparent and inclusive manner, with the (typically) many different constituencies affected by the interconnection project receiving sufficient opportunity to provide input into the planning process, the result may be a spur toward democratization. This occurs as the groups providing input to the planning of the interconnection see that their “voices” have been taken into account in the planning process. Also, as officials overseeing the planning process see that providing opportunities for input from different groups of society are not only not-so-difficult to manage, but provide useful substantive input and smoother implementation of the project as well, government actors may learn to offer such opportunities for input in other contexts. Demonstrations of participatory decision-making in the context of planning and implementing power grid interconnections can thus have positive impacts on public participation in other important decisions affecting a country, as well as on venues and methods for participation in decisions by the constituent groups of society, and by the public as a whole in the nations involved[88].

Another way that grid interconnections may promote democratization is through their effects on power supplies. Where grid interconnections help bring stable electricity supplies to communities that previously had poor or no electricity, opportunities for education and obtaining news are increased, which can in turn prepare more citizens to participate meaningfully in democratic processes.

4. Grid interconnections may have a positive impact on political stability

In addition to providing light to learn by, grid interconnections, to the extent that they help bring electricity to under-served regions, may enhance political stability by offering opportunities for employment, education, and medical care in areas where lack of these necessities previously caused dissension between the government and local groups. Increasing the standard of living of populations, especially rural or suburban populations, through electricity provision (and other programs) helps to slow migration to urban centers, helps to alleviate poverty, and thus mitigates the political difficulties and social tensions involved in providing for the urban poor.

Of course, much is predicated on how the benefits of grid interconnections are distributed within a nation. Grid interconnections may also enhance political stability (here literally defined as the longevity of political regimes) in an arguably less-than-optimal fashion. If the proceeds from a grid interconnection are disproportionately distributed to a political elite who use them to secure their own political base, political stability is the net result, but the resulting stability is arguably not sustainable in a social sense, and does not lend itself to democratization. Avoiding this pitfall requires a transparent and inclusive process for planning not only how an interconnection will be developed and operated, but how the economic and social benefits of the interconnection (income from power sales or improved electricity supplies) will be distributed among the populace of a nation.

C. POTENTIAL POLITICAL LIABILITIES OF INTERNATIONAL GRID INTERCONNECTION

Depending, again, on how interconnection agreements are structured, and often on the nature of the interconnection itself, international grid interconnections may also become political liabilities to one or more of the host countries. Possible political liabilities include mostly domestic issues, such as the possible impacts of arrangements needed to secure power line assets, the political fallout if there is found to be graft related to an interconnection project, and the possibility of power lines being held “hostage” by militant groups, as well as international issues related to the increased economic interconnection between the countries participating in the project. As with possible political benefits of grid interconnections, the potential that these liabilities will manifest themselves is very case-specific, and depends in large part on how the process of deciding upon, designing, building, and operating a grid interconnection is handled.

1. Protection of the power line as an excuse for internal political oppression

One of the responsibilities of the nations participating in an international power grid interconnection will, as noted in Chapter III, be the securing of the portions of the interconnection infrastructure in their countries from damage caused by humans. Protecting the power line and adherence to agreements to do so could, in some cases, be used by authorities as an excuse for internal political oppression. For example, if a power line for an interconnection project passes through an area where a local group has historically had political conflicts with the central government, securing the power line infrastructure might be used by the central government as a rationale for preemptive action against the local group. Because the power line connecting the nation’s grid with electricity supplies (or demand) from another nation is clearly an important national asset, a government may find it more expedient to explain restrictions on or other moves against local populations in terms of security of the power line than in terms of advancing political goals, even if the latter is the actual overriding concern.

2. Effects of interconnections on international political relations

The presence of a grid interconnection between countries has the potential to give one country unwanted political leverage over another. If the dependence on the grid interconnection and the electricity and income it delivers is disproportionate between the interconnected nations (such as between a poorer, smaller country and a more industrialized, larger country), the potential exists for the country with less at stake in the interconnection to use power trades, and the threat of shutting off power flows, as a political tool to extract concessions from or otherwise exert political power over its interconnection partner or partners. Similarly, when an interconnection must pass through a third country to move electricity from the selling country to the major consuming country, the third country can potentially hold the interconnection "hostage" to its political demands by threatening, implicitly or explicitly, to interrupt power flows relied upon by the other partners.

3. Heightened vulnerability to political difficulties in another nation

Heightened involvement or dependence on another country's electricity sector may make a nation participating in an electric interconnection more easily affected by its neighbors' (or partners') internal and external political situation. For example, if a country depends on buying power from a neighboring nation that is gripped by internal strife, the purchasing country may find itself unwillingly drawn into political, or even military, conflict with one or more of the opposing groups seeking political power in its trading partner. This situation is not limited to electricity trades—dependence on trade in other commodities can also induce neighboring countries to "take sides" in their neighbors' internal conflicts, which they might have otherwise ignored (or played a much less active role in). Unlike many other commodities—food, minerals, or finished goods, for example—electricity cannot be stored (in significant amounts, anyway), and must be transported using relatively expensive, exclusive infrastructure that cannot be re-routed at will. As a result, a country dependent on electricity imports or exports may see no choice, if the electricity trade is threatened, than to become involved in the other nation's internal (or even international) conflicts to protect its own interests.

4. Proceeds from the interconnection may provide a temptation for diversion by political decision-makers

For an electricity exporting country, proceeds from the sales of electricity over a major international grid interconnection can easily reach into the hundreds of millions of US dollars per year. Some of these funds can be diverted openly and for legitimate purposes other than paying for the costs of providing electricity (subsidizing electrification, job creation efforts, or other development programs, for example) but in countries where controls on the behavior of public officials are weak, these substantial financial flows may offer the temptation for graft. Where proceeds that should be public funds are diverted for personal use, the result may be concentration of political power in the hands of those who have taken the funds, at the expense of other groups, thus altering (or helping to artificially maintain) the political balance of power in the country. Similarly, in both countries importing and exporting power, decision-makers may also be tempted to accept bribes or "kickbacks" from companies that are awarded contracts for constructing or maintaining power lines and/or the power plants used to feed them. As with diversion of proceeds from electricity sales, such bribery schemes have the strong potential to artificially alter the balance of political power, as well as to make the electricity supplied by the interconnection more expensive, to reduce the quality of the interconnection infrastructure, or both. For both handling of proceeds from an interconnection and handling of supply contracts related to interconnection infrastructure, a transparent, clear, accountable, and thoroughly reviewed process for arranging for and handling financial transactions is the best way to ensure that the diversion of funds and its political ramifications do not become problems.

5. Political costs of power line protection

As noted above, the power lines and other infrastructure needed for grid interconnections are expensive investments and, when operating, are relied upon to provide power and income.

As such, they must be protected from attack. Power lines may run for hundreds of kilometers through fairly remote areas, including areas where central government control is naturally weak. In addition to the potential for oppression of local populations in the name of providing such protection, as noted above, the need to protect power lines and other infrastructure from militant local groups may put a central government in a weaker political position relative to the local groups, essentially offering the potential that the power line will be used as a tool for financial and/or political extortion by local groups against the government. This may result in the central government's granting political concessions to the local group (such as greater autonomy from central jurisdiction, or a reduction in vigilance against illegal activities such as smuggling, poaching, or bribery) than it would otherwise be obliged to do. A related potential political problem may arise if the government uses the distribution of proceeds or power from the interconnection as a tool to nominally enforce protection of interconnection infrastructure in local areas, but in a way that punishes local groups for actions or positions not related to the power line at all.

Given that many nations in the developing world consist of a patchwork of traditional ethnic, religious, tribal, or other allegiances, and that the remote areas where many resources that might be used for power generation are often not under the control of a strong central government, some form of political extortion related to the protection of interconnection infrastructure may often be possible, even unavoidable. The possibly most effective means of handling this eventuality from a sustainable development perspective involves, as noted above, from the outset maintaining a transparent process for decision-making regarding the interconnection, and involving as many local groups as possible in deciding how the interconnection should be configured and how the costs and benefits should be shared, so that stakeholders in the construction and operation of the interconnection have thoroughly "signed off" on (approved) how the interconnection will be built and run. This approach, together with strict adherence to the agreements made and continuous consultation among the partners in the agreements, will help to keep political conflicts to a minimum.

6. Political costs of tariff rationalization

One result of grid interconnection, for some countries, may be to force state utilities that have previously been relatively isolated from the requirements of rational pricing and cost recovery to pay much more attention to the balance of costs and income. This will be especially true when hard currency payments are required for power imports. The result may be that subsidies routinely given to certain groups (low-income consumers, agriculture, or industry, for example) may no longer be sustainable[89]. The political cost of changing these subsidies may be substantial. This does not mean that cross-subsidies from one set of consumer groups to another may not continue even when an interconnection is in operation—the point here is that the presence of an interconnection, and the financial transparency that it will require in order to pay all costs related to the interconnection, will likely force utility managers to undertake tariff overhauls that may be, in the short term, politically difficult or unpopular.

D. TYPES OF POLITICAL COOPERATION REQUIRED

The planning, establishment, and operation of international electric grid interconnections requires a wide variety of agreements between nations, as well as within nations. Though some of these agreements are of a more "legal" or "technical' nature, most also of necessity have political elements as well. Augmenting the discussion of required legal agreements described in Chapter III of this report, some types of agreements with political elements are mentioned below, so as to underscore that political will and a degree of political organization and internal cooperation is needed in order to come to terms on the necessary accords to allow the construction and operation of interconnections.

1. Agreements in principle as to sharing power resources

The forging of legal agreements for sharing power resources between countries requires political agreement between the two governments that such sharing of resources would be mutually beneficial. Coming to such a political agreement which, after all, gives each country a degree of leverage over the economy of the partner country, may in itself be difficult, particularly in regions where neighboring countries have a history of rivalry. In addition, internal political discussions are needed within each country participating in the interconnection to ensure that, on balance, an interconnection is a wise use of national resources, and that the different political actors within the country are content with (or at least resigned to) the types of long-term international responsibilities that a grid interconnection implies.

2. Agreements on moving forward with the interconnection project

After agreements on sharing resources have been reached, the task of defining the specifics of the interconnection project and of selecting design/construction contractors begins. This task also has political implications associated with it, as the nationality and identities of the selected contractors may be subject to political preference in one or more of the power-sharing nations. Though ideally the best-qualified contractors offering the most reasonable price should prevail in an open bid process, in practice political forces may well play (or may attempt to play) a role in how contractors are selected. The routing of the power line or lines for the interconnection is also likely to be a subject that will involve political maneuvering, as nations and groups within nations attempt to secure routings that will bring those groups the most benefit, or to avoid routings that are deemed undesirable.

3. Agreements as to how firms included in the interconnection project will be paid, and by whom

Once contractors are selected, political agreements among the countries cooperating in the project will have to be reached on how the contractors will be paid, and by whom, as control over the finances of the project is both an economic and a political issue[90].

4. Agreements as to how benefits and costs of the project will be shared

It is highly likely that international, national, and even local political agreements will be needed to decide how the benefits, as well as costs, of power line interconnections will be shared both between countries and between groups within countries. Cost-sharing will require similar political agreements. Political agreements within countries relating to the distribution of power line benefits may result in trading off of political “favors” within groups so as to secure the agreement of all stakeholders.

5. Agreements as to how the interconnection will be operated and secured

Political as well as legal agreements will need to be reached between nations and among groups within nations to determine how interconnection infrastructure, including power lines, will be operated and secured. Agreement on the governance of an independent interconnection operator, or acceptance of one party or another as an operator, will be a matter of political as well as legal debate. If power line security, for example, is provided by personnel from another country (or even from another region within the same country), political agreements as to the type and scope of security operations carried out by those personnel would need to be in place.

6. Agreements as to the sharing of information necessary to plan, operate and protect the interconnection

The operation of a grid interconnection, and even the planning of the interconnection, requires that the countries planning the interconnection have access to information about the electrical system of the other countries. In many instances, this may include access to information that is deemed politically "sensitive" by one or more parties. As such, political agreements must be reached on what information is to be shared, and how and when it is to be shared, between different countries and different groups. Similarly, the securing of a power line or other interconnection infrastructure may require that countries, and certainly groups within countries, share information on the activities of sub-national groups. Obtaining and providing access to such information will involve political discussion, particularly as such information gathering and transfer may have ramifications for civil liberties.

E. NATIONAL/REGIONAL ATTRIBUTES THAT HELP TO SUPPORT GRID INTERCONNECTION

If the weighing of political costs and liabilities such as those noted above, together with the many other costs and benefits of international grid interconnection, tend to favor grid interconnection in a specific instance, there are a number of national and regional attributes that will smooth the path to full acceptance and development of interconnection infrastructure and institutions. First among these attributes, as noted in a document prepared by the "E7" Group of Utilities, is the political will to engage in cooperation with other countries:

> "Above all, it is fundamental to ascertain and enhance the political will for cooperation. This may actually be considered a preliminary condition to the entire implementation process. Until now in fact, regional electricity cooperation and integration has developed first and foremost in countries with political cooperation experience." [91]

The same source continues:

> "A clear commitment from the decision-makers involved in the development of an interconnection project is crucial in order to secure the support of international investors. Moreover, strong "political" support from all public and private participants is considered the single most important element for a successful interconnection project."[92]

Some of the many national political attributes that favor interconnection projects are described below.

1. Culture of regional cooperation

Nations that have a history of cooperation with neighboring countries on other issues are more likely to have both the political inclination and political structure in place to make an interconnection a reality. Countries that have active trade with their neighbors in key commodities, share transportation links, have active programs of cultural exchange, and work together politically to secure international benefits for their region are more likely to look favorably on grid interconnection opportunities and to be able to smoothly negotiate and implement the agreements needed to make interconnection work.

Perhaps the ultimate example of a set of countries where the existence of multiple ties in many sectors developed over a very long period has helped smooth the way to grid interconnections are the countries of Europe. Here active trade—including trade in commodities and services, transport linkages, and active cross-border trade in non-electric energy products—has been carried out for many decades (indeed, for some commodities, for many centuries), and political cooperation between countries is routine. At present, electricity trade between the nations of Europe is very active, with some countries depending on neighbors for significant portions of their power needs. Indeed, an integrated European market for electricity is a stated long-term goal of the European Union's European Electricity Directive of 1997[93]. The "E7" Group's document on Regional Electricity Cooperation and Integration states:

> "In fact, integration is a self–feeding process; this is quite clear in the European Community, as it started developing to coordinate coal and steel production, then was implemented as an integrated body, and now fosters the integration of electric power markets in a single market." [94]

2. Culture of long-term planning

Electric grid interconnections are long-term investments, with lifetimes of 30 years or more, and also require significant lead times for design, impact studies, and construction (among other activities). As a consequence, countries with a culture of long-term policy planning may find it easier to cope with the demands inherent in integrating a grid interconnection into their national long-term electricity sector development strategies. In addition, countries where long-term planning is a tradition generally will be better able to understand the political requirements of adhering to long-term agreements, such as power sales and purchase contracts.

3. Clarity of internal energy policy goals, and internal energy sector structure

In addition to a culture of long-term planning and demonstrated successful participation in external cooperative ventures with other countries, internal political agreement among those setting policy as to energy policy goals (and attitudes about cooperation in general) also smooth the way to international agreements on grid interconnections. This assumes, of course, that the goals agreed to are consistent with international grid interconnection. Internal agreement on energy policy goals can be reached either by a process of internal discussion of options among interested parties, or simply by policymakers excluding the views of those who may not agree. These two approaches to reaching clarity on energy policy goals may have similar ramifications for the initial agreement on making a grid interconnection, but different ramifications for the long-term internal acceptance of the interconnection by some of the country's citizens.

The structure of a country's energy sector, and its electricity sector in particular, may also serve as an attribute in favor of grid interconnections. If the companies (state or private) that operate the electric system in a nation considering power imports are not politically threatened by the prospect of having some electricity supplies come from outside, and/or if the wholesale supply of electricity in a country already operates in a competitive market atmosphere, the politics of agreeing to a grid interconnection are likely to be more favorable. On the export side of the picture, if a country has state or private companies that both are anxious to participate in power exports and have political leverage in their nation, that nation is more likely to successfully pursue grid interconnection opportunities.

4. Willingness to formally ratify and adhere to international agreements

The "political will" necessary to implement a grid interconnection includes the willingness to enter into long-term contracts. The extent to which a national government has shown a prior willingness to ratify and adhere to international agreements in other areas (including agreements on trade, transport, criminal justice, the environment, and security) is an indicator to potential interconnection partners of the government's potential political reliability in maintaining its part of the bargain in an interconnection arrangement.

5. Demonstrated willingness to enter into cross-border trade in a key commodity like electricity

More specifically, nations that have shown the political will to enter into agreements for cross-border trade on key commodities are arguably more likely to be politically motivated and able to internally justify agreements to share power. Countries that depend on each other for a large proportion of their supplies of petroleum products or food, for example, are more likely to find that a co-dependence on a similarly vital commodity such as electricity is not a significant departure from politics as usual between the nations.

6. Common membership in strong regional organizations

Countries that together belong to regional institutions active in promoting trade and regional cooperation—the Asia-Pacific Economic Cooperation group of Pacific Rim nations (APEC), ASEAN (Association of Southeast Asian Nations) and the League of Arab States are examples here—are more likely to have common experiences in cooperation that will help to further the prospects of international grid interconnections. In addition, existing cooperative agreements formed under the charters of regional organizations to which potential interconnection partners belong may help to provide the basis for interconnection agreements themselves, and help to smooth the way for internal political acceptance of grid interconnections.

F. BARRIERS TO POLITICAL COOPERATION ON GRID INTERCONNECTIONS

For each of the national or regional attributes that help to support grid interconnections, there are potential characteristics that, conversely, serve as barriers to political cooperation on cross-border grid interconnections. Rivalries between nations or between sub-national groups, internal disunity as to energy policy goals or other political issues that affect prospects for grid interconnections, and other differences between nations all may present hurdles that the proponents of a grid interconnection project must overcome.

1. Longstanding national rivalries and related distrust

Many adjoining nations share histories of rivalry. These may include border disputes, lingering antipathy from wars fought recently or long ago, disputes over refugees, or other differences. Lingering mutual mistrust among the nations of Northeast Asia, for example, stemming from the Japanese colonial period and World War II, the Russo-Japanese War, and even earlier, have arguably slowed the development of cooperation in energy resource sharing among the countries of that region. Most of the countries of the Northeast Asia region also have unresolved disputes with at least one neighbor over territorial claims. Russia, with immense energy resources in Siberia and the Russian Far East that remain largely untapped (and a need for foreign exchange earnings) and the Republic of Korea, with rapidly growing demand and access to both technology and financing, could be natural energy trading partners. To date, however, they have been stymied from building grid interconnections in large part by the ongoing political (and quiescent military) confrontation between the Republic of Korea (and its allies) and the Democratic People's Republic of Korea, which sits geographically between the two countries[95]. These types of lingering political issues may or may not directly affect negotiations for grid interconnections, but can be sources of distrust that affect the negotiation process.

2. Religious or tribal rivalries and related distrust between nations

In addition to purely political differences between nations, religious or tribal rivalries between nations may also prove to be barriers to interconnection agreements. Governments of neighboring countries, when controlled largely by groups with a history of conflict in the region, may have distrust for their potential trading partners that make grid interconnection negotiations more difficult.

3. Internal national disunity

Where one or more of the nations potentially involved in a grid interconnection suffers from national disunity, it becomes more difficult to reach lasting agreement among all of the relevant parties on how the benefits and costs of interconnection will be distributed. Major disagreements among groups of citizens in a country, whether the government itself is strong or weak (but especially in the latter case), not only make it politically more difficult for the stakeholders in the country itself to agree on energy policy goals and on the utility of (and distribution of benefits from) a grid interconnection, but make it harder for potential partner countries to trust the country's government to keep its promises in interconnection agreements. In addition, once an interconnection is built, a country suffering from serious internal conflict is less likely to be able to keep interconnection infrastructure secure, which is both a practical and political consideration for potential partner countries.

4. Substantially different political systems between countries

Where countries considering electric grid interconnections have significantly different political systems, this difference can also serve as a barrier to reaching political agreement on a grid interconnection. Apart from any existing regional rivalries or ethnic/tribal/religious mistrust, countries with different political systems may trust each other less simply because their governments, probably including their legal and economic systems, do not operate in the same way. In these instances, reaching agreement on the details of how an interconnection is to be implemented and governed becomes more difficult, as each party must learn how its counterparts' governing systems work in order to be sure of how interconnection agreements will be carried out.

5. Emphasis on national energy self-sufficiency and internal energy sector organization

Some countries, as part of national overall and energy policy, have an emphasis on national energy self-sufficiency that may preclude or serve as a barrier to grid interconnections. Countries with political systems that are xenophobic (tend to shun other cultures), or which simply feel, based on national ideology, that their energy security and/or general security interests are better served by maximizing use of internal resources, to the exclusion of other resources, are arguably less likely to be willing to enter into agreements to share electricity resources.

Even countries with a rich tradition of trading in energy and other commodities may have an internal electric system organization that acts to restrain prospects for trade in electricity. Independent of any potential overall economic gain to the country to be achieved by electricity trade, if politically powerful state or private utilities in a potential electricity importing country see an interconnection as reducing their own economic and/or political standing, those organizations likely are going to resist grid interconnections and the resulting diminution of market share, electricity rates/revenues and/or national importance that would (they perceive) come with it. In Japan, for example, electric utilities have historically had electricity tariffs that are among the highest in the world. The availability of imported power in large quantities, for example from the Russian Far East (via undersea cable), would ultimately (assuming a degree of market liberalization) serve to reduce wholesale power rates and would likely drive down retail tariffs as well. A similar situation exists in Japan in the gas sector, where largely non-interconnected, local gas companies have enjoyed secure service territories and charged high prices, and thus have had limited political or economic incentive to support either pipeline imports of natural gas, or the national pipeline grid that would be needed to distribute such imports. As a result of these market arrangements, Japanese utilities historically have had an economic disincentive to promote power imports, though these attitudes may be changing. As one researcher of the impacts of trading of electricity and other energy commodities in Japan has noted:

> "One of the highest national priorities in practical specific terms is to resolve the global competitive threat to Japan's electric power utilities companies. Although this is a little-recognized clash, there will be a dynamic change in the Japanese power industry as corporate executives recognize the challenge because they are willing to develop global strategies and energy policy."[96]

As the (historical) Japanese situation indicates, the internal organization of the power sector, particularly in the potential importing partner or partners in an interconnection scheme, can serve as a significant political barrier to grid interconnection, to the extent that the managers of the utility systems, first, have political clout (as is often the case) and, second, see grid interconnections as providing a competitive threat to the utilities' earnings and/or political standing.

6. Corruption and political interference in the power sector

If a country's electricity sector has a history of corruption and political interference, potential interconnection partners may find the prospects of working with utilities in that country unattractive. For interconnections to operate efficiently and provide the desired benefits to the participating governments, power sector reform (including the building of a culture of transparency and open, consistent dealings in the electricity sector) must be promoted, and such a culture may prove difficult for those in power to adopt if corruption has been the rule. Margaret Njirambo Matinga writes:

> "A fear of the negative implications of PSR [power sector reform], which is often equated to privatisation and related to structural adjustment programs, as well as a misunderstanding of the role of the regulator, further create powerful motivation for continued political interference in the power sector. This undermines the more important and necessary objectives of regional integration."[97]

Ms. Matinga continues:

> "Credibility of energy governance systems will also play a crucial role in attracting FDI [foreign direct investment] and in building a credible and functional power pool. Lack of a history of independent regulation in the power sector means regulatory performance is often assessed by proxy. The likely proxy indicator for assessing the credibility of the new governance structures is the government itself. Unfortunately, most governments in the region have a history of lack credibility in adhering to legal requirements; a reputation rubs off various sectors. Politically, even though a lot of countries have changed their governments to democratic leadership, the new leadership is either too new or unstable to be trusted. In addition, precedent regimes tend to have an influence on current regimes. The challenge is then for the region to develop governance systems, policing and enforcing mechanisms and practices that ensure credibility. The LRF [legal and regulatory frameworks] should also clearly support the creation of credible institutions and send the appropriate signals to the investor community through adherence to the regime."[98]

A problem related to corruption at the "user" end of the electricity system, rather than at the "supplier" end, is illegal consumption of power. In many developing countries and countries with economies in transition, theft of electricity through often dangerous illegal connections to the distribution network, sometimes referred to as "non-technical losses", is a major problem[99]. As distribution utilities become more transparent in their dealings with customers and power sellers and buyers, as a result of interconnection and/or other reforms, it is likely that the imperative to reduce the amount of electricity not paid for (by significantly upgrading metering and billing systems, as well as cracking down on illegal connections) will be extremely strong, if not in fact mandated by interconnection sales agreements.

G. OVERCOMING BARRIERS TO POLITICAL COOPERATION (NATIONAL AND INTERNATIONAL)

Each potential international grid interconnection (and each potential national party to that interconnection) will present its own unique set of attributes enhancing the prospects of a successful project, as well as its own unique set of barriers that must be overcome. A set of generic approaches to overcoming barriers to political cooperation in grid interconnection projects, utilizing national political attributes that favor interconnections in the process, are listed below[100]. These approaches stress transparency, being inclusive in negotiations within and between countries, sharing information, making sure to distribute project benefits (and costs) fairly, and using international institutions to aid in the process. The "E7" Group's Regional Electricity Cooperation and Integration compilation includes the following statement, which summarizes an approach to overcoming political barriers:

> "There are political barriers to market integration, mainly the absence of political trust, as well as political concern that international trade would jeopardize the social objectives assigned to the electricity supply industry. On the contrary, giving higher profile to the economic, social and environmental benefits that electricity market integration could yield and spending efforts to persuade political actors to meet and agree on common rules may be a starting point for regional electricity cooperation and integration." [101]

1. Make all dealings between parties in the agreements open and transparent

Many potential political barriers exist or are propped up by internal or international traditions of secrecy and “backroom” negotiations. Making sure that all dealings between parties to the potential interconnection agreements are as open as possible is a key element of overcoming internal and international political barriers. Here “open” means that all draft agreements and related documents are available for convenient public review, that meetings between parties are announced in advance and open to representatives of all potentially affected groups, and that processes in the negotiation of the agreement are laid out beforehand as a working agenda (though subject to modification as the process proceeds) that indicates points at which comments from interested parties can be provided, and how those comments will be taken into account at major decision points.

2. Include all affected parties in early stages of project formulation and throughout the project

Additional political barriers to interconnection are the result of the exclusion—deliberate or intended— of certain groups that are likely to be affected by the interconnection project, from the process of discussion of the interconnection. Including potentially affected parties from the early stages of grid interconnection negotiations can help to lower barriers due to internal political disagreements. Potentially affected parties, including representatives of local governments and leaders of organized groups within the specific geographical areas that would host infrastructure related to the interconnection, should be invited to attend meetings where interconnection prospects are discussed and to provide input on interconnection plans. In some cases, funds may need to be provided so that these groups have the capacity (including capacity for analysis of the local impacts of interconnection options, for example in the form of hired consultants and/or of trained internal staff) to participate meaningfully in discussions. Establishing an “Advisory Group” for the interconnection project, with membership by representatives of all national and sub-national groups potentially affected by the project, is one way to accomplish inclusion of different groups in a structured and not overly-burdensome manner. This Advisory Group would then be included in (or, in some cases where discussions are particularly detailed, briefed on) discussions related to the project, and would have at least some authority to accept, reject, or force changes in decisions made by managers of the interconnection project.

3. Establish protocols for data collection and distribution to parties that require data

As noted in Chapter I and in other chapters of this report, proper planning of an electric grid interconnection requires information from a variety of sources. For example, information is needed on the transmission systems of the interconnected countries, on the power plants operating in the grids to be interconnected, on long-term plans for power system development in the interconnected countries, and on the forecasts for power demand in the countries to be linked. Similarly, information on the costs of electricity from different sources must be provided so that the economic costs and benefits of grid interconnections can be adequately gauged. The different political groups likely to be affected by grid interconnections will need access to these types of data, and to the results of models run with these types of data as inputs, in order to ensure that they are fully included in the decision-making process, and that each group feels that the project decision-making process is suitably transparent. Providing access to data will require that protocols for data collection and dissemination be established and followed throughout the project development process. The need for "open and profound analysis [involving all of the nations involved in the interconnection] of system responsibilities" was noted in the case of the "Baltic Ring" project among the countries of Northern Europe[102]. This type of analysis and the coordinated, well-founded planning that is needed to support an interconnection (particularly one that also functions with competitive markets) require open, timely access to system and planning (for example, demand forecasting) data for all of the groups that are stakeholders in the interconnection.

Establishing data collection and dissemination will also, in most cases, include making sure that the organizations tasked with obtaining the needed data in each country are adequately staffed and funded. In addition, dispensations should be made so that groups that will be reviewing data have adequate training and/or have expertise at their disposal so as to be able to make an adequate review of the information made available.

4. Make sure that benefits and costs of the project are fairly distributed

While ensuring transparency in project planning and development and making sure to include all major relevant groups in the interconnection planning process are key elements of overcoming political barriers to grid interconnections, political support may still be lacking unless the costs and benefits of the interconnection are demonstrably fairly distributed. This means that the groups responsible for evaluating the project in each country must first come to general agreement on *what* the costs and benefits of the project are—including both quantifiable and not-easily-quantifiable aspects of the project. Next, a "base-case" assessment needs to be prepared describing *who*, in terms of countries, geographical areas within countries, local groups, and other parties to the interconnection arrangements, will receive overall project benefits, and how the overall benefits will be distributed. Following a similar assessment of how project costs will be distributed, negotiations among parties will take place to ensure that project costs and benefits, to the extent that they can be identified, are fairly balanced among the interconnected countries and among the interest groups within countries. This process of negotiation could, for example, attempt to ensure that any environmental or social risks taken by hosts to power line or other project infrastructure would be compensated by benefits designed to assist in the sustainable development of the area (for example, consistent electricity supplies at affordable rates), while making sure that project costs would be fully paid[103].

5. Work with and through respected international organizations and other intermediaries where appropriate

Common membership in regional and international organizations was noted above as an attribute that can help countries contemplating a grid interconnection find common ground for agreement. Working with and through international and regional organizations in formulating and planning projects, including using support from such organizations to obtain analytical assistance for the various parties to an interconnection, can help to overcome political barriers to agreements, particularly when the international or regional organizations involved are demonstrably neutral in their approach. The involvement of international financial institutions, in particular, can provide the initial spur to overcome reticence to begin discussions of interconnection with neighboring countries, as well as being a trusted source of technical expertise and, ultimately, project funding. The "E7" Group of Utilities describes the role of regional political organizations and/or international institutions in overcoming the reticence of national utilities to interconnect as follows:

> "In developing countries, the situation is quite different [from the current situation in North America, Europe, and Japan, where low load growth, trends toward smaller generation capacity, and market reorganization considerations dominate] . Economies of scale have not been captured, the hydroelectric potential is not harnessed, and the demand for electricity is expected to double or triple over the next 25 years. There is an urgent need for organizing the expansion of the energy system at a regional level. The corresponding investment to be made in the electric sector is generally out of reach of the governments' financial capability. The experience of E7 countries shows that the development of transnational electricity trade — a key component of the least-cost process for developing the electricity sector — will not be "naturally" favored by state-owned and controlled electricity utilities. If a high level of regional integration is to be achieved, a strong political push needs to be given, either through political regional organizations or by international institutions.[104]"

6. Case study of interconnection projects and proposals

A large hydroelectric project in Nepal, designed to feed demand in India and China through an interconnection, is a case where a proposed grid interconnection (and a large export-oriented power plant to feed it) failed to reach the implementation phase in part because of perceived inequitable distribution of benefits and a lack of political cooperation. In 1996 the Nepalese Government first invited Houston-based Enron Corporation to talks regarding the Karnali Hydroelectric Power Project to be built high in the Himalayan Mountains. The multi-billion dollar, 10,800 MW project was designed to export electricity to India and China. Nepal is a poor country with immense but largely untapped hydroelectric potential. Currently only 0.5 per cent of the country's believed hydro capability is utilized, and only 15 per cent of the country's 22 million people have access to electricity.[105] Developing its water resources through the building of large hydro facilities is a major focus of the Nepalese Government. However, strong opposition from both international lenders and its own civil society regarding the construction of large dams has made this desire difficult to achieve. In 1995, the World Bank abandoned its plans to loan $175 million for the Arun III hydro project, stating that the Nepalese government should instead focus on building smaller hydro initiatives, and after several rounds of negotiations Enron withdrew its plans for the Karnali dam project.

The Enron example is an interesting case. Although largely supported by the government, protests by various local civil society organizations played a significant role in causing the deal to flounder and for Enron to eventually pull out. Both Enron and the Nepalese government were committed to pushing the project forward; however, neither the government nor Enron Corporation had much experience in regards to building and operating a large hydroelectric facility, and therefore concerns were expressed regarding the poor project development of the Karnali dam.

Through debates and discussions with government officials, civil society groups raised several issues related to the construction and operation of large scale hydro plants such as this one. One of the major concerns expressed by these groups was in regards to who would be legally responsible, the Nepalese Government, Enron or a combination of the two, for the expected large resettlement and environmental mitigation costs associated with the project. Civil society groups referred to ongoing problems in these areas prevalent in many of the smaller scale hydro projects in Nepal to express their similar concerns over this proposed "mega-dam".

A second major concern was in relation to who would actually benefit from Enron's proposed hydro project. Often, large scale export-oriented electricity projects do not create any forward or backward economic linkages. Therefore, Nepali civil society groups feared the local population would not receive any real economic benefit from the project. An additional concern was related to the lifespan of large reservoir dams in the Himalayas. Due to the hydrology and geography of many rivers in this region, the life-span of large reservoir dams in reality may be significantly shorter than expected or planned[106]. These concerns, raised by various civil society groups, stemmed in part from the poor project development of the Karnali Hydro dam, and were an influential factor leading to Enron's pulling out of the project and the project's being abandoned.

H. SUMMARY AND CONCLUSION

International electric grid interconnections may bring political benefits to the interconnected countries including increased experience and political comfort with international cooperation, more reasons to avoid conflict with neighbors, increased democratization (depending, in part, on how the interconnection is designed and administered), and an increase in internal political stability. On the other hand, in some cases, the existence of an interconnection may be used as an excuse for internal political oppression, may give one of the interconnected countries more political and economic leverage over another, may entangle countries in each others' internal affairs, may provide potential for political graft, and may entail significant political costs for power line protection.

Designing, constructing, and operating power line interconnections require political cooperation both between and within countries on a number of fronts, including:

(a) Agreements in principle as to *sharing power resources*—political agreement between the two governments that such sharing of resources would be mutually beneficial;
(b) Agreements on *moving forward* with the interconnection project, including agreements on contractor selection, power line routing, and other major decisions;
(c) Agreements as to how interconnection *project contractors will be paid*, and by whom;
(d) Agreements as to *how the benefits and costs of the project will be shared* between and within nations;
(e) Agreements as to how the interconnection infrastructure will be *operated and secured*, including agreement on the governance of the interconnection operator;
(f) Agreements as to the *sharing of information* necessary to plan, operate and protect the interconnection.

Countries sharing the political will to cooperate on a grid interconnection are those most likely to reach such agreements smoothly and in a timely manner. Countries sharing a culture of regional or international cooperation, having a culture of active long-term planning and clear energy policy goals, having shown a previous willingness and ability to ratify and adhere to international agreements, sharing a history of cross-border trade on key commodities, and having common membership in strong regional organizations are those most likely to be able to reach political agreement on grid interconnections. Political barriers to interconnection between countries, on the other hand, can include longstanding national rivalries or territorial disputes, religious or tribal rivalries between nations, internal political disunity, substantially different political systems and traditions, an emphasis on national energy self-sufficiency to the exclusion of other options, and an internal energy sector organization that may be politically at odds with an interconnection project.

Given these potential political benefits, costs, national attributes favoring agreements, and barriers to cooperation, some of the potential overall strategies for reaching the necessary political agreements (many of which have technical, legal, economic, social, and/or environmental aspects as well) include:

(a) Emphasizing transparency in negotiations related to grid interconnections;

(b) Including all (or at least all major) potentially affected parties in the early stages of project formulation, and continuing to solicit the input of all parties on key decisions throughout the project;

(c) Establishing clear needs and protocols for collecting and distributing quantitative data and other information needed for project design and for the accurate estimation of project costs and benefits;

(d) Fairly distributing project costs and benefits among project participants and groups affected by the interconnection;

(e) Working with and through international and regional institutions, including international financial institutions, to help smooth the path to political agreement, as well as to assist in providing the capacity for all groups to contribute meaningfully to decisions related to the interconnection.

I. RESOURCES FOR FURTHER ANALYSIS

1. Selected references

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"Guidelines" and "Module 1" volumes of Regional Electricity Cooperation and Integration (RECI): E7 Guidelines for the pooling of resources and the interconnection of electric power systems. Hydro-Quebec, October 2000. Pprepared by the E7 Network of Expertise for the Global Environment, and available from http://www.e7.org/Pages/Pu-Papers-GuidelinesRECI.html.

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[88] The converse to this argument is that if a grid interconnection planning process fails to allow for input from affected parties, it has the potential to alienate groups from the democratic process, as described in the sub-section that follows.

[89] Won-Cheol Yun, notes the political and financing implications of power subsidies as follows "…the current level of electricity tariffs in the Russian Federation and South Korea are below marginal costs and the services are implicitly and heavily subsidized. These will introduce additional uncertainties for investment toward power sector". "A Strategic Approach for Electric Power Cooperation in North-East Asia" presented at the APEC Study Centre Conference Asia Pacific Economies: Multilateral vs Bilateral Relationship, held in Hong Kong, 19-21 May 2004 and available as http://fbweb.cityu.edu.hk/hkapec/Conference/Papers/Won-Cheol.pdf.)

[90] Contractor payment protocols in interconnection projects financed entirely or in part by international financial institutions, however, may be prescribed by the lender, and thus not (or not as) subject to political agreement.

[91] The "E7" Group of representatives of large utilities from the G7 group of industrialized nations. Regional Electricity Cooperation and Integration (RECI): E7 Guidelines for the pooling of resources and the interconnection

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of electric power systems, (Hydro-Quebec, October 2000), “Guidelines” volume, p. 8. These documents are available from http://www.e7.org/Pages/Pu-Papers-GuidelinesRECI.html.

[92] Ibid.

[93] See, for example, Michael. Pollitt, “Electricity Market Integration and Liberalization”, A European Market for Electricity? Monitoring European Deregulation 2, Part I, Ch. I, Romesh Vaitilingam, ed.. (London, Centre for Economic Policy Research, 1999).

[94] Regional Electricity Cooperation and Integration (RECI) , op.cit., “Module 1, RECI Feasibility volume”, p. 29.

[95] Won-Cheol Yun, op.cit.

[96] Fumio Arakawa, “Restructuring Needed for IEGI”, presented at the Workshop on Power Grid Interconnection in Northeast Asia, held in Beijing, China, 14-16 May 2001, p. 5. Available as http://www.nautilus.org/archives/energy/grid/materials/arakawa.pdf.

[97] Margaret Matinga, “Pooling African Power: Challenges and Issues in a Reforming and Integrating Southern African Power Sector,” presented at the Workshop on Monitoring Regional Integration in Southern Africa, held at Midgard Lodge, Windhoek, Namibia, 12-13 June 2004, and available as http://www.nepru.org.na/Regional%20Intergration/Power%20sector%20integration.pdf.

[98] Ibid.

[99] The M. Matinga article referenced above includes the estimate that non-technical losses in the countries of Southern Africa average 35 per cent (presumably of net generation), versus a “world average” of 2 per cent. Southern Africa is hardly the only region where this problem exists. The author of this report has encountered similar rates of illegal consumption in other countries, including countries in the Middle East.

[100] Many of these strategies are echoed, for general applications, in a document by the African Development Bank/African Development Fund entitled Bank Group Policy On Good Governance, (July 1999), and available as http://www.afdb.org/pls/portal/docs/PAGE/ADB_ADMIN_PG/DOCUMENTS/LEGALINFORMATION/BANK_GROUP_POLICY_ON_GOOD_GOVERNANCE.PDF.

[101] Regional Electricity Cooperation and Integration (RECI) , op.cit., “Module1, RECI Feasibility volume”, p.29.

[102] Baltic Ring Electricity Co-operation Committee (BALTREL), Towards a Common Electricity Market in the Baltic Sea Region, (2002), p. 21. Report co-Financed by the European Commission, and available as http://www.baltrel.com/Reports/Baltrel_021202.pdf.

[103] For example, it may be necessary to subsidize the cost of electricity delivered over the power line to some groups (rural low-income households, for example) compensated by higher prices paid by other groups, in order to find a balance that fairly apportions the benefits of the project and promotes sustainable development. This may result in some price distortion and make competition in electricity provision more difficult. The issue of subsidies to low-income consumers is discussed briefly in Margaret Matinga, op.cit., p. 5.

[104] Regional Electricity Cooperation and Integration (RECI), op.cit., “Module 1, RECI Feasibility volume,” p. 27. A footnote to the quoted statement in the source document notes that since the electricity market in Europe has, in fact, been dominated by national utilities, with the exception of trade in hydroelectric energy in Scandinavia and from Switzerland, electricity trade in Europe has largely occurred as a result of “planning errors” which resulted in poor matches between required capacity and actual capacity in some nations, particularly overcapacity of nuclear generation in France.

[105] Gopal Sharma, *Nepal to Invite Enron for Power Talks*, The Financial Express, 13 August 1997, available as http://expressindia.com/fe/daily/19970813/22555633.html .

[106] Pandey, Bikash, Dams and Civil Society in Nepal, Serial No. 031. TheWorld Commission on Dams, 2000, available as http://www.dams.org/kbase/submissions/showsub.php?rec=soc031. The potentially reduced lifespan of hydroelectric reservoirs in the Himalayas is due in part to the combination of an actively changing geology and sometimes violent rainfall, causing sediments to flow into reservoirs in huge quantities and quickly reducing reservoir capacity.

V. SOCIAL ASPECTS OF GRID INTERCONNECTION

A. INTRODUCTION

Power grid interconnections have the potential to affect the societies in the interconnected countries in a number of ways. These impacts on societies can be positive or, particularly in instances where the costs and benefits of interconnection are not fairly distributed, negative. As a result, power grid interconnections can contribute to sustainable development, can damage prospects for sustainable development or, because grid interconnection infrastructure may cover thousands of kilometers, have both types of impacts in separate places and among separate peoples. This chapter describes some of the potential social benefits of international grid interconnections and of the electric power and income such interconnections can provide. Also described are the potential social costs and liabilities of grid interconnection, as well as approaches to enhance the social benefits and reduce the social costs of grid interconnections.

B. POTENTIAL SOCIAL BENEFITS OF GRID INTERCONNECTION

The potential social benefits of international electric grid interconnection can be divided into those benefits derived from improved access to affordable electricity, benefits related to the economic gains associated with electricity sales, and benefits related to cooperation between the interconnected societies. The "E7" Group of utilities describes some of the social benefits of grid interconnections as follows:

> "Optimized electric power systems should improve reliability and quality of service, while allowing lower tariffs. Lower electricity rates, achieved through regional electricity cooperation and integration, will foster increased regional growth. The interconnection of isolated electric power networks throughout a region will enhance rural electrification programs. Local needs of individuals, families, communities and businesses will be better met through the increased availability of electricity." [107]

In order to ensure that a grid interconnection results in sustainable development in the region, capacity building may often be necessary to ensure that benefits (and costs) of an interconnection are accounted for properly, and to ensure that the interconnection is operated in such a way as to contribute to sustainable development.

1. Potential social impacts of grid integration related to improved electricity supply

Many of the clearest social impacts of international grid interconnections are related to either the effects of improved electricity supply in parts or all of the interconnected nations, or effects of lower costs of electricity supply in countries receiving power and/or receiving avoided generation capacity benefits.

Improved electricity supply may take the form of more reliable electric service in areas that are already served by the national grid or grids, or greater availability of electric service made possible by the grid interconnection—such as extension of grid electricity into previously non-electrified areas. Improved and especially new power supplies offer the potential to contribute to sustainable development through creation of employment opportunities[108], thus assisting with poverty alleviation. Better electricity supplies for agricultural uses, such as water pumping and crop processing, can lead to higher crop yields and better harvesting processes, potentially improving both farm incomes and food availability. Electricity for pumping water for household needs may yield much-improved water quality and quantity (with their attendant health and welfare benefits) and free householders (often women and children) from what is often many hours spent transporting water from remote supplies. More hours of electricity (or new supplies) can yield improved educational opportunities, through enhanced availability of high quality light for studying or evening classes. Provision of electric light in the evening also enhances opportunities for home businesses, as well as improving the availability of information via radio, television, and possibly phone and computer. Where electricity supplies are sufficient for use for cooking (and electric cooking appliances are affordable), use of (sometimes scarce, and usually polluting) biomass and wood fuels can be avoided, with an attendant reduction in the amount of time householders, especially women and children, are obliged to spend collecting fuel. Where both better lighting and information are combined with more time to use them (through reduction in the time needed for tasks such as bringing in drinking water or wood, washing clothes, or purchasing lamp oil) the social benefits of electricity provision can be compounded.

Better electricity supplies help to make possible the storage of medicines and vaccines that must be refrigerated in rural areas, contributing to better health care. Improved lighting and access to electricity of better quality also allows the operation of electrical health care devices, and allows medical practitioners a better view of their patients. Where electric on-grid lighting replaces costly energy sources such as kerosene and diesel oil used in lamps, or small disposable electric batteries, significant savings in the household energy budget can occur, freeing income for use in education, health care, or home business investment. Reduced use of non-electric fuels for lighting may also result in significant improvements in indoor air quality, with related health benefits[109].

The social benefits described above imply that grid integration allows rural on-grid electrification and/or improves grid reliability. While both of these outcomes may be stated goals of an interconnection project, these outcomes might not necessarily come to pass unless care is taken in designing and implementing plans for the distribution of the benefits of the project to different stakeholder groups.

2. Potential social benefits of electricity-related income and savings

For a country that is primarily a seller of electricity in a grid interconnection project, one of the key motivations of participation is to be able to export energy resources in the form of electricity, in exchange for (typically) hard currency income. This income from energy resource exports has the potential to be a “lever” to provide social benefits from the interconnection to the people of the exporting nation. For example, income from electricity exports, in addition to paying for the net costs of increasing electricity production (including capacity expansions and fuel extraction, if any), can be partially devoted to social concerns, such as developing local businesses and industries, building/improving schools and health care facilities, or subsidizing electricity provision to low-income residents (including assisting with the development of renewable local electricity sources), each of which can help to contribute toward sustainable development. In distributing these types of social benefits, care should be taken that benefits are provided in particular to those groups and areas likely to be most affected by the interconnection, such as groups in areas hosting new transmission lines or generation facilities. If the entity selling electricity through the interconnection is a state-run company, these sorts of income transfers for social purposes would be internal to the government, and thus (theoretically) relatively straightforward. If the entity selling electricity is a private company, some sort of export tax or license fee may be necessary to collect funds to be used to provide social benefits in electricity exporting countries.

These types of social impacts derived from additional electricity sales can also apply when overall cost savings result from the interconnection project. Public and private monies that would otherwise (in the absence of the interconnection) need to have been spent on electricity generation and transmission capacity may be devoted instead to addressing social needs like those described above. Further, to the extent that an interconnection avoids the need to construct and operate new power plants, the potential social impacts of those plants—including the social and health impacts of pollution from the plants, changes in land use, and arguments among groups over power plant siting (the "not in my back yard" phenomenon)—may be avoided. The avoided social impacts of a project are, of course, extremely site-specific.

3. Ancillary social benefits of construction of interconnections and related infrastructure

The construction of grid interconnections, and of new power plants to feed interconnections with power, may open up economic and social opportunities for residents in nearby areas. For example, roads or railroads built to serve a power line may provide access for isolated communities to markets for local goods, to income from tourism, and for improved access to education and medical care. Similarly, the opening up of routes used by new transmission infrastructure can provide opportunities for the installation of other infrastructure, such as telecommunications and internet cables and access (which themselves may provide a spur to economic development)[110].

4. Fostering cooperation between the interconnected societies

As noted in earlier chapters of this report, the planning, design, construction, and operation of a grid interconnection between two (or more) nations require cooperation of many different types. High-level political cooperation between countries is certainly necessary, but a potential benefit of grid interconnection is also that the project can serve as a spur to cooperation at the societal level as well. If the grid interconnection serves to provide (or enhance) a political bridge between nations, the bridge can be used to foster social exchanges in sports, education, and culture, for example, promoting understanding between societies. Similarly, enhanced trade in other commodities between countries could follow from the experience in trading electricity, bringing citizens from the interconnected societies into additional contact in the process. In addition, grid interconnection activities, such as power line construction and maintenance or construction of new power stations, may bring workers from the interconnected countries together, depending on how the contracting crews are selected. Working together on projects of clear mutual benefit, working in ways that provide person-to-person contact between people of different nationalities, is an excellent method of building trust and understanding between peoples from different societies.

5. Building social capacity to participate in grid interconnection decisions

A key to making sure that the potential social benefits of international electric grid interconnections are fully realized is to ensure that the various stakeholder groups that should benefit from the interconnection have the capacity to fully participate in the project decision-making process. As a consequence, in most projects there will be a need for capacity-building to allow groups within societies to evaluate the costs and benefits of grid interconnection from their own perspectives. As noted in Chapter IV, this may take the form of direct training of members of the groups in the types of analysis needed, and/or may involve making available funds for hiring assistance. For example, representatives of local groups will need training in the economic analysis of energy projects so that they can read and comment on project design reports, training in environmental analysis so that they can review environmental assessments to determine how interconnection infrastructure will affect their groups (and the areas the group uses), and training in law sufficient to allow them to review legal agreements to determine what the impact of those agreements will be on their group. If human capacity is built to the extent that all social groups with stakes in how the interconnection is configured, and in how the interconnections costs and benefits are distributed, are able to meaningfully participate and have an adequate voice in the decision-making process, that social capacity building in and of itself can be considered a major benefit of the interconnection process.

6. Building capacity for socially-beneficial management of grid interconnections

As with participation in the interconnection decision-making process, once interconnection infrastructure is built, interconnection operators (and those who will oversee them) will require training in order to allow management of grid interconnections in a manner that contributes to sustainable social development. This will mean, for example, that grid operators must be aware of commitments made to different social groups and must make sure that the way in which the interconnection is operated is consistent with those commitments. This includes (for example) commitments such as availability and reliability of electricity supply in rural areas, the distribution of income from electricity sales via the interconnection to meet social needs, and coordination with local groups to avoid conflict when maintenance of interconnection facilities in areas used by those groups is required. The types of human capacity building required here may be largely the development and implementation of guidelines for the operation of interconnection, training of interconnection/grid operators in the implementation of those guidelines, and management training to make sure that the guidelines are periodically reviewed and continuously enforced to ensure that social benefits are as promised (or as much so as possible).

C. POTENTIAL SOCIAL COSTS/LIABILITIES OF GRID INTEGRATION

A well-designed, well-managed grid interconnection can bring significant social benefits to the nations that it serves. Similarly, if configured or operated in a way that ignores significant social needs or potential impacts, a grid interconnection may have significant social costs or liabilities for one or more stakeholder group. Examples of such costs include the impact of a power line on access to resources used by a group, potential “upstream” (in the fuel chain) impacts of a grid interconnection, and the potential for a grid interconnection to increase reliance on outside resources.

1. Potential isolation of local residents from key resources

The infrastructure that must (in many cases) be constructed to complete an international electric grid interconnection may have the potential to significantly affect local communities. New large power lines, for example, may cut across traditional hunting, gathering, or agricultural areas. The need to keep vegetation low for safety reasons may result in loss of habitat for the plants or animals on which local communities depend, thereby putting social (and economic) stress on those communities. The need to secure the power line may result in the denial or restriction of the right of local peoples to travel from one side of a power line to another, thereby restricting the resources the communities can use for their livelihood, as well as their social access to communities on the other side of the power line. Further, if a power line or other interconnection infrastructure is located in areas inhabited by indigenous peoples with little contact with the outside world, unless handled with extreme care, power line operation is likely to expose local societies to unwanted and potentially destructive outside influences, with social conflict between locals and others entering the area for work related to the interconnection a distinct possibility.

2. Potential construction-related social impacts of grid interconnection

Power line interconnections often are designed to connect remote resources with large centers of electricity demand. As such, construction of interconnection infrastructure, like interconnection operations, can affect societies in the remote areas they transit by exposing those societies to unwanted outside influences. An increase,in social problems such as drug and alcohol addiction, prostitution, disease, and other social problems among those local populations may result from encounters of construction personnel (and, for example, migrants providing services to construction teams) with locals.

3. Potential “upstream” impacts of grid interconnection

For countries entering into grid interconnection agreements mainly to export power, the social impacts associated with energy sector changes needed to provide power for export (that is, changes “upstream” in the fuel chain) have the potential to be costly in social terms. One type of social cost here is the displacement of communities due to the impacts of new power plant construction and operation. Although fossil-fueled power plants (particularly those using coal or other solid fuels) may require considerable land area, the classic example of displacement of communities results in cases where hydroelectric facilities are built to provide power for exports over an interconnection. Here the hydroelectric dam, and the reservoir that forms behind the dam, may easily displace many thousands of people—whole towns and even cities—with loss of communities, agricultural resources, and even cultural resources such as antiquities sometimes the outcome. An example of the social and other impacts of population displacement due to construction of a hydroelectric plant (providing power for both domestic use and exports) in Ghana was summarized as follows by E.A.K. Kalitsi as follows:

> “In Ghana, significant environmental and social issues were faced with the development of the Akosombo Lake on the Volta River for hydropower generation and other multi-purpose uses. The creation of the Lake and the regulation of the floodwaters of the Volta River brought in its wake numerous negative impacts on the lives of the communities living upstream and downstream. The major impact was socio-economic arising from the dislocation and resettlement of about 80,000 people from about 740 villages. Different ethnic groups with a wide linguistic diversity lived within the flood basin. This tremendously compounded the problems of resettlement. The resettlement effort also represented a formidable and physically challenging task due to the nature of the basin that was inundated. The basin was not only large; it was isolated, difficult to access and had minimal infrastructure. The basin was also unhealthy with insect-borne diseases like malaria, river blindness, and sleeping sickness and water borne diseases like bilharzia. Incidence of some of the water borne diseases like bilharzia and hookworm increased.”[111]

Historically, hydro dam construction has sometimes led to substantial social and political conflict between predominantly urban groups who benefit from the electricity and groups in the reservoir area who suffer from displacement and economic disruption, or between relocated populations and existing populations in the areas to which the displaced populations are relocated. In addition, hydroelectric facilities affect the availability of water resources both in the area of the dam and downstream—potentially even across borders. The International Rivers Network, in a short summary of the effects of several existing hydroelectric dams in the Mekong region of Southeast Asia (where efforts to build interconnections are underway), cite social impacts such as population displacement, loss of food sources and income through effects on agriculture, irrigation, and fisheries, changes in the availability of drinking water, increases in the incidence of water-borne diseases, and other impacts[112]. Other types of "up-the-fuel-chain" impacts on societies may accrue, for example, when fossil fuel deposits in remote areas are exploited to fuel an export-oriented power plant or plants. Particularly for solid fuels, but also for petroleum or natural gas fuel extraction as well, the development of mines and gas and oil fields can bring with them loss of local resources and environmental impacts that yield social impacts. These extraction operations also result in more exposure of local populations to "outsiders", increasing (in many cases) the potential for unwanted changes in society and for social conflict.

Another classic type of negative social impact associated with the construction of energy facilities of many types (and which may occur in energy facilities needed to "feed" electricity exports) is the "boomtown" phenomenon. Here, as populations—often thousands or tens of thousands—of workers are imported to a remote area to work on a large project such as a hydroelectric dam, major power plant complex, or oilfield, a "town" forms, populated by immigrants to the area as well as more local residents who seek to provide for the needs of the workers. Often in the past, the planning of such towns has been poor (or non-existent), and as a result social, health, safety, and other services have been lacking. Some of the problems associated with Coari, an energy-facility-related "boomtown" (in this case, an oil and gas transport terminal) in the Brazilian Amazon have been described as follows:

> "…Coari itself has suffered the typical problems of a boom town: rapid population growth (from 50,000 to 60,000 within a period of 12 to 18 months, the majority men from other parts of Brazil seeking employment), prostitution also of children (2% of babies born in Coari have 11- to 14-year old mothers), drugs (Coari is the so-called regional capital of drugs), increased crime, a high prevalence of venereal diseases and AIDS (the medical staff at the Coari hospital are alarmed as they feel they have absolutely no control), and high rates of unemployment due to immigration (the terminal has 700 workers, most of whom are not from Coari)." [113]

As construction on the energy facility is completed, workers begin to leave, and those that have made their living serving the workers lose their sources of livelihood. Those that cannot return to rural areas for one reason or another (including, for example, that their towns have been displaced by the energy facilities) may be obliged to migrate to the margins of large cities in their search for employment, adding to social problems (including unemployment, poverty, and crime) there[114].

4. Potential for grid interconnection to increase dependence on outside resources

For countries importing power, and even for countries implementing a grid interconnection in order to be able to share generation resources and reduce the costs of developing new generation, the use of imported power in most cases will increase social dependence on outside resources. One impact of this dependence may be reduced incentives for development of possibly promising local resources. Reduced development of local resources may be a net positive social impact if development of those resources would yield net negative social impacts, but in some cases development of local resources may provide higher social benefits and lower social costs—in the form of additional local jobs, and reduced exposure to outside influences, for example. Also, reliance on electricity from an interconnection, rather than on local sources of energy, may put the communities served by electricity from the interconnection, and the country importing power, at risk of political, economic, and social events beyond local or even national control. If the cessation of power flows from a relied-upon interconnection is rapid and permanent, the social impacts of suddenly short supplies of electricity may be significant, and the costs and other arrangements (over-cutting of fuelwood, or massive new investments in power plants, for example) needed to supply needs for energy services in the short run to make up for lost supplies may be unsustainable and cause irreversible environmental, economic, and social damages.

In a paper from the Workshop on Regional Power Trade (held in Kathmandu, Nepal, in March 2001), the following point is made about the possible security risks of relying upon power supplies from another country:

> “Power interconnections have been shown to enhance the security and reliability of a country’s electricity supply through the access of support during times of emergencies and the sharing of the provision of operating reserves. However, attendant with the development of power interconnections is the counter-balancing concern over the dependence on imported power and possible electricity shortages as the result of others actions. In a regionally operated system, where all the power-generating facilities are responding to the demands of that regional system, each of the individual areas within that region loses a certain amount of autonomy and self-determination.” [115]

D. APPROACHES TO REDUCE SOCIAL COSTS OF GRID INTERCONNECTION

Though the potential social benefits and costs of grid interconnections are likely to be highly case-specific, there are several generic approaches that can help to reduce the social costs of grid interconnection, reduce the risk of social damage from grid interconnection arrangements, and/or increase the social benefits derived from interconnections. These approaches are summarized below.

1. Locating power lines in existing transmission or transport corridors

To the extent possible while maintaining safety and reliability standards, power lines used for international grid interconnections should be placed in existing transmission corridors—or, if that is not possible, in existing transport (road or rail, for example) corridors. Placing new power lines in existing rights-of-way minimizes additional disturbance to the ways of life of local remote communities and tends to minimize additional environmental disturbance (and the attendant social costs of environmental problems) related to power line construction and operation. Placing new transmission lines in existing corridors is also less likely to stimulate social conflict over the interconnection project, as the power line will not traverse as much virgin territory[116].

2. Making sure that benefits and costs of power projects are shared equitably

As stressed earlier in this chapter and in Chapter IV of this report, a key to reducing the political and social difficulties involved in reaching agreement on grid interconnections is to make sure that both the costs and benefits of a project are equitably shared by the various stakeholder groups. This means ensuring that communities hosting a power line or other infrastructure related to grid interconnection are compensated for doing so, that investors and contractors are adequately but not excessively paid for their financial services and work, that benefits can clearly be shown to be flowing to the societies sponsoring the power line, and that within the societies receiving benefits, specific individuals and groups do not end up taking more than their share of benefits. By sharing project costs and benefits equitably among project stakeholders in a transparent manner, social conflicts related to the project should be minimized.

3. Integrating planning of grid interconnections with overall long-term power planning

Benefits and costs of any project must be calculated relative to reference and alternative sets of conditions—that is, relative to what would have happened, or could have happened, in the absence of the project. This means, for example, demonstrating an interconnection project's viability relative to other ways of providing importing countries with the same power supplies using internal (or other imported) resources, or demonstrating that the project has net benefits relative to some other means of providing stability and sufficient generation capacity to the national grid. Providing a thorough, long-term analysis of the interconnection project in the context of what would have happened without the interconnection, or would have happened had other major options for providing electricity services been pursued (for example, emphasizing decentralized local generation and energy efficiency options), is a key way of allowing the different social stakeholder groups to clearly evaluate whether the interconnection option is in their best interest, and to be assured that other options with possibly greater social benefits have not been overlooked. Planning should also be undertaken jointly, or collaboratively, by the countries potentially involved in the interconnection, to ensure that all relevant project costs and benefits are taken into account to the extent possible[117]. In fact, planning of grid interconnections should be integrated not only with long-term power planning, but with long-term planning for the provision of energy services (not just fuels) and of social development in general. This point was stressed in a 2004 DESA Report on sustainable energy consumption in Africa, prepared by Stephen Karekezi, Jennifer Wangeci, and Ezekiel Manyara, and is illustrated in the following quote:

> "The key challenge facing Africa is not to increase energy consumption per se, but to ensure access to cleaner energy services, preferably through energy efficiency and renewable energy thus promoting sustainable consumption. Unlike most industrialized countries which progressed from traditional energy to unsustainable conventional energy consumption patterns and which are now struggling to move to a sustainable energy path, Africa could, in a number of sectors, leapfrog directly from current traditional energy consumption patterns to sustainable energy options. Consequently, the careful examination of energy consumption patterns and trends in Africa should be of interest to the sustainable development community." [118]

Long-term planning here does **not** (and practically, cannot) mean specifying every element of the future development of an electricity system, but rather means a process requiring frequent updating and iteration, through which overall directions for a power system (or energy sector, or society) are chosen. The actual implementation of these directions may be up to government agencies, the private sector, or a combination of the two, guided by overall policies[119].

4. Planning interconnection construction and operation so as to maximize social benefits and avoid social costs

Social issues should be included as considerations when planning how grid interconnections, and the power plants that will feed them, are to be constructed and operated. For example, where there are temporary work camps to provide lodging for workers on construction projects, the camps should be planned, preferably with input from local residents, so as to minimize their negative impact on nearby communities and on the resources upon which those communities depend. The operation of hydroelectric plants should take into account the seasonal needs of downstream communities for water to support agriculture and fisheries so as to minimize social and environmental impacts on locals. If local communities are promised benefits from the interconnection in return for hosting electric facilities, those benefits should be supplied promptly so as to build trust and minimize the potential for social conflict. In the context of the construction of hydropower plants, E.A.K. Kalitsi expressed the need for continuous monitoring and assessment of social situations as follows:

> "There is a need for detailed and extensive studies during the planning phase long before implementation time. These studies will have to be intensified during implementation and the results used to modify the plans. With environmental data gathered before and during construction and filling stage, it was possible to plan mitigation and eradication measures, to monitor and assess changes in the ecosystem. Such planning should not be static but be adjusted as new conditions arise. In spite of initial and environmental and social studies before start of construction when it came to actual implementation the information available was found to be inadequate. This is how VRA [the Volta River Authority] found itself compelled to provide its dislocated people with uniform core houses not related to the value of their properties affected; or failing to clear from the reservoir areas tree stumps scattered all over the lake creating serious hazards to navigation or failure to provide for settlers and riparian communities to share in the benefits of electricity. The lesson here is that there is need for continuous planning and evaluation in order to implement a satisfactory program to mitigate any negative effect of hydropower developments." [120]

Full consideration of both upstream and downstream riparian rights and water-sharing issues should be a part of any interconnection project that will involve changes in hydroelectric capacity or operation.

5. Ensuring that all affected parties are brought into and can participate meaningfully in the decision-making process

Social groups with a demonstrable voice in a decision on an interconnection project are arguably less likely to come into conflict with authorities or each other over the project later. In order to promote the participation of all potentially affected social stakeholders in an interconnection project, it is necessary to create a forum, starting early in the project formulation process, where stakeholder groups can learn about the project and participate in decisions. Moreover, representatives of stakeholder groups must be provided with the resources (education, expertise, and the wherewithal to attend meetings, for example) that they need to fully participate in the project planning process. Finally, post-project (including post-relocation) monitoring of the social situation of peoples affected by the project is needed in order to anticipate and minimize any ongoing or developing problems.

Many of the suggestions above, and many other techniques germane to the development of grid interconnections in such a way that related social problems are minimized, are described in the document Conflict-Sensitive Business Practice: Guidance for Extractive Industries, published by International Alert[121].

E. SUMMARY AND CONCLUSION

International grid interconnection projects may yield significant social benefits to some or many groups in the nations participating in the projects. Among these benefits are:

(a) The social benefits derived from *enhanced supplies of electricity*. An international interconnection may help to provide better power quality, more reliable power, and more widespread availability of electricity to communities. Greater availability of affordable electricity can provide more opportunities for education, improvements in health care, development of employment opportunities, and reduction of difficult and labor-intensive tasks, all of which can contribute to sustainable development;

(b) The social benefits derived from *national and/or local income related to electricity sales.* If carefully and equitably distributed, and particularly when spent toward meeting social development goals such as improved education, health care, and housing, agricultural improvement, and creation of employment opportunities, the income to power exporting countries from an interconnection agreement may have many positive social impacts;

(c) A spur towards additional *cooperative activities between the interconnected societies*. Successful operation of a grid interconnection may provide the experience and incentive for interconnected countries to embark on additional cooperative activities, including cultural exchanges and trade in other commodities, that can help improve social (as well as political) relations between the countries.

Some of the potential social costs and/or liabilities of grid interconnection are:

(a) The *isolation of local residents from resources*. The presence of a power line or other types of infrastructure used in grid interconnections may partially or totally separate local groups physically from the water, land, forest, agricultural, social and economic (local towns and markets), and other resources that they use regularly;

(b) *Unwanted outside influences* resulting from the process of *construction of interconnection infrastructure*. This can cause, social problems in formerly isolated local populations, ranging from alcoholism to violence;

(c) Other *fuel cycle impacts* on social groups. For electricity exporting countries, the construction and operation of power plants built to feed an interconnection, and of the fuel supply infrastructure that feeds the power plants, may have significant social impacts. Displacement of populations by new facilities (particularly hydro facilities) can be considerable and can lead to social problems such as out-migration from rural areas to the margins of cities, under-employment, and dislocation from ancestral lands;

(d) Increased *dependence on outside resources.* For electricity importing countries, use of electricity provided via an interconnection from a neighboring country can reduce the incentive to use local resources, can increase the vulnerability of communities to cuts in power supply that are outside of the control of the community and the nation, and can reduce the preparedness of the community to deal with electricity shortages.

Some of the general approaches to making sure that social benefits of interconnections are maximized, and social costs are minimized, include, as noted above:

(a) Locating new power lines *in existing transmission or transport corridors* as much as possible;

(b) Ensuring that the social *benefits and costs are fully considered* as part of any project impact or feasibility study, and making sure *that social and economic benefits and costs* of the project are equitably distributed;

(c) *Integrating* consideration of grid interconnections as a part of overall *long-term electricity* sector (and general energy sector) *planning*;

(d) *Planning the construction and operation* of grid interconnections so as to *minimize social costs* and ensuring that *social benefits are delivered as promised* and continuing planning and assessment studies even after the grid integration project is completed and avoiding "developer's fatigue", in which "the enthusiasm which characterized the initial socio-economic activity waned when this should have been the time for such activities to have been accelerated"[122];

(e) Implementing *capacity building to allow different social stakeholder* groups to meaningfully participate in *investigating and deciding upon grid interconnection options*, and in *planning* for grid interconnection construction and operation.

F. SELECTED RESOURCES FOR FURTHER ANALYSIS

Karekezi, Stephen , Jennifer Wangeci, and Ezekiel Manyara, Sustainable Energy Consumption in Africa. Prepared by the African Energy Policy Research Network (AFREPREN/FWD) for DESA (Nairobi, Kenya, 14 May 2004), p. i (Executive Summary). DESA Final Report, available as http://www.un.org/esa/sustdev/sdissues/consumption/Marrakech/EnergyConsumption.pdf.

Kalitsi, E.A.K. "Problems and Prospects for Hydropower Development in Africa". Presented at the Workshop for African Energy Experts on Operationalizing the NGPAD Energy Initiative, held in Dakar, Senegal, 2 – 4 June 2003, and available as http://www.un.org/esa/sustdev/sdissues/energy/op/nepadkalitsi.pdf.

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The UN Global Compact (http://www.unglobalcompact.org) includes a number of references, case studies and tools in areas relevant to assessing the social benefits and costs of business ventures (such as interconnections and other large energy ventures) and their impacts on sustainable development. Issues such as transparency and multi-stakeholder processes are covered in documents (including the Banfield et al document referenced below) available on the UN Global Compact site.

Banfield, Jessica, Adam Barbolet, Rachel Goldwyn, and Nick Killick. Conflict-Sensitive Business Practice: Guidance for Extractive Industries. Prepared for International Alert, (London, International Alert, March 2005) and available as http://www.international-alert.org/pdfs/conflict_sensitive_business_practice_all.pdf.

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[107] The "E7" Group of representatives of large utilities from the G7 group of industrialized nations, Regional Electricity Cooperation and Integration (RECI): E7 Guidelines for the pooling of resources and the interconnection of electric power systems, "Guidelines volume". Hydro-Quebec, October 2000., available as http://www.e7.org./Pages/Pu-Papers-GuidelinesRECI.html.

[108] Some employment opportunities may arise as a direct result of the interconnection, including both short-term employment in constructing interconnection-related facilities, and longer-term employment related to maintaining the interconnection infrastructure and distributing electricity from the interconnection.

[109] Additional potential benefits from the use of electricity in the place of other household fuel are described in Itai Madamombe, "Energy Key To Africa's Prosperity: Challenges in West Africa's Quest for Electricity", Africa Renewal, Vol.18 #4, January 2005, available as http://www.un.org/ecosocdev/geninfo/afrec/vol18no4/184electric.htms.

[110] Briony Hale, "Africa's Grand Power Exporting Plans" (BBC, October, 2002); available as http://www.globalpolicy.org/socecon/develop/africa/2002/1017power.htm, The impact of telecommunications expansion—particularly the expansion of mobile phone networks—on economic development is treated in the article "Calling Across the Divide" in The Economist, 12-18 March 2005, p. 74.

[111] E.A.K. Kalitsi , "Problems And Prospects for Hydropower Development in Africa", presented at the Workshop for African Energy Experts on Operationalizing the NGPAD Energy Initiative, held in Dakar, Senegal, 2 – 4 June 2003, p. 13; available as http://www.un.org/esa/sustdev/sdissues/energy/op/nepadkalitsi.pdf.

[112] International Rivers Network, "Trading Away the Future: the Mekong Power Grid" (Berkeley, CA, International Rivers Network, June 2003); available as http://www.irn.org/programs/mekong/030620.powergrid-bp.pdf.

[113] "Urucu hydrocarbon project" Amazonia (European Working Group on Amazonia – EWGA, 1997); available as http://www.amazonia.net/Articles/116.htm.

[114] The "boomtown" phenomenon and other issues related to development of energy resources is described briefly in Sustainable Development International, Impact Assessments: Preventing slow burn issues from bursting into flames, (Henley media Group Ltd., 13 April 2005) available as http://www.sustdev.org/index.php?option=com_content&task=view&id=424&Itemid=49.

[115] World Energy Council, "Regional Electricity Trading: Issues and Challenges", presented at the Workshop on Regional Power Trade, held in Kathmandu, Nepal, 19 March 2001; available as http://64.224.32.197/Publications/shean.pdf; quote is from page 6.

[116] There also are likely to be cost savings when locating a transmission line in an existing right-of-way, including lower costs for clearing of the route and providing access to the line. These costs may be offset, of course, by higher costs caused by the use of a routing that is less direct.

[117] The costs and benefits of "joint planning" are described in the "Module 4: Integrated Operational Planning: Optimal Conditions" volume of Regional Electricity Cooperation and Integration (RECI), op.cit.

[118] Stephen Karekezi, Jennifer Wangeci, and Ezekiel Manyara, Sustainable Energy Consumption in Africa. Prepared by the African Energy Policy Research Network (AFREPREN/FWD) for DESA. DESA Final Report (May 2004), p. i (Executive Summary). Report available as http://www.un.org/esa/sustdev/sdissues/consumption/Marrakech/EnergyConsumption.pdf.

[119] Examples of procedures for the demand- and supply- (resource evaluation) side elements of long-term planning incorporating consideration of interconnections can be found in the "Module 2: Market Analysis" and "Module 3: Resource Development" volumes of Regional Electricity Cooperation and Integration (RECI), op.cit.

[120] E.A.K. Kalitsi, op.cit., pp. 13-14. This reference also provides a useful summary of the need for other types of ongoing planning, studies, and mitigation activities related to the social and environmental impacts of large hydroelectric facilities, with the experience in Ghana as background.

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[121] Jessica Banfield, Adam Barbolet, Rachel Goldwyn, and Nick Killick, Conflict-Sensitive Business Practice: Guidance for Extractive Industries (London, International Alert, March, 2005); available as http://www.international-alert.org/pdfs/conflict_sensitive_business_practice_all.pdf.

[122] E.A.K. Kalitsi, op.cit., p. 15. The quote is based on experience with large hydroelectric projects in Ghana.

VI. ENVIRONMENTAL ASPECTS OF GRID INTERCONNECTION

A. 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, possibly, the production and use of other fuels. Evaluating and keeping account of the full-fuel-cycle environmental impacts of grid interconnections are important elements 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 transmission facilities. In energy planning in general, environmental considerations have sometimes received less emphasis 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[123].

B. 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 where and when certain power plants are run 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 existing 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 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, while 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 electric 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 and impacts avoided by the project relative to other means of providing the same energy services as the interconnection) includes construction of the power line and related infrastructure, operation of the power line, and construction and operation of the power plants feeding the grid interconnection (or plants that are avoided by the use of the line). In addition, there are impacts related to fuel supplies for and wastes from power plants.

C. 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[124]. 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[125].

Consideration of the net impacts of grid interconnections on air pollution involves consideration of net emissions of 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 non-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:

(a) *Local air pollutants* typically 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;
(b) *Regional air pollutants* move beyond the immediate area in which they are emitted to affect a larger area. Regional air pollutants include those that play a role in acid precipitation and can have a variety of impacts on health, ecosystems, and structures;
(c) *Global air pollutants*, particularly greenhouse gases, can affect global climate.

Individual air pollutant species may have impacts on 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.

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 in 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[126].

(a) Carbon monoxide

Carbon monoxide, or CO, 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.

(b) Sulfur oxides

Sulfur oxides, of which sulfur dioxide (SO_2) 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 both acute and chronic exposure to the gas causing death of part or all of a plant, 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.

(c) Nitrogen oxides

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 problems 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.

(d) Volatile organic compounds

Volatile organic compounds, or VOCs, are sometimes referred to as "hydrocarbons" or "non-methane VOCs". The many different species in this class of compounds result 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 importance include PAH (polycyclic aromatic hydrocarbons), POM (Polycyclic Organic Molecules) and other VOC species whose molecular structure gives them significant biological activity. 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.

(e) Particulate matter

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}", denotes the fraction of particulate matter with particle diameter of 10 microns (10×10^{-6} meters) or less, and "$PM_{2.5}$", denotes 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 C.2 below.

(f) Heavy metals

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 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).

(g) Radioactive emissions

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 by the populations exposed to radiation following the explosion of the nuclear bombs over Hiroshima and Nagasaki in Japan, and by the 1986 Chernobyl reactor accident in the Ukraine[127]. 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 defects, 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 that 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 (RFE) 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[128].

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[129].

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[130].

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 or snow,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[131] (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 acidic, 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[132]. 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[133].

As noted above, sulfur oxides are produced during combustion of coal, which contains varying amounts (about 0.5 to 5 or more per cent) 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[134].

A paper by Prof. Zhu Fahua provides a review of the air pollution impacts, including local and regional (acid gas) emissions, of thermal power plants in use in China. [135] 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.

The potential of transmission interconnections to displace emissions 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 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 and evaluated 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 ,be causing changes in regional and even global climate in addition to their impacts as indoor and local air pollutants [136]. 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"[137]. Modeling results suggest that recent higher incidences 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 experienced warming, may be the results of the impact 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.

3. Global air pollution impacts

International electric 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 4.5° C with a doubling of carbon dioxide concentrations, relative to pre-industrial levels[138]. Given current trends in emissions of greenhouse gases, 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 2° 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), 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[139].

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 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.

> "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." [140]

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:

> ". . . 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." [141]

Assessment studies have shown how climate changes and higher sea levels 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:

(a) Changes in temperatures;
(b) Changes in the amount of precipitation;
(c) Changes in the timing of precipitation;
(d) Changes in plant growth rates;
(e) 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;
(f) Changes in forests due to changes in temperature, precipitation, and evaporation;
(g) Changes in the distribution and prevalence of plant and animal pests and diseases;
(h) Changes in biodiversity and species distribution—all of the changes above have the potential to alter the distribution and range of plant and animal species, including both domesticated crops and livestock and native flora and fauna;
(i) Changes in ocean temperatures and their effects on ocean productivity, including the productivity of and growth rates of reef ecosystems;
(j) Changes in sea level 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 rise in sea level. 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 a rise in sea level and will 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 that 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 for partial funding through the Global Environment Facility (GEF) or Clean Development Mechanisms (CDM). These possibilities are discussed in greater detail in section I of this chapter.

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[142].

News reports based on recent studies suggest that Trans-Pacific air pollutant transport is widespread in destinations, sources, and the types of pollutants involved[143]. 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.

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:

(a) An assessment of which *power plants*, or classes of power plants, *will run more, and which will run less*, in which locations, 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, financial, 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;

(b) 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 or transported, and the quantity of refined products produced and stored;

(c) 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;

(d) *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 of 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 provides a sample set of emission factors for power plants (and, in the case of biofuels, residential stoves) using different types of fuels[144]. These emission factors are expressed in terms of mass of emissions per unit of input fuel;

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

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

D. IMPACTS OF GRID INTERCONNECTION ON WATER POLLUTION AND WATER QUALITY

To perhaps a greater extent than air pollution impacts, significant water pollution impacts—both positive and negative—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.

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 rights-of-way. These potential impacts include:

(a) 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;
(b) Erosion from access road construction and, during power line operation, from vehicle traffic on existing and new access roads;
(c) Impacts of heavy machinery operation in rivers and wetlands on water quality;
(d) Lubrication oil and fuel leakage and other emissions from heavy machinery used in power lines;
(e) Accidental spills and other emissions of liquids used in transmission infrastructure, including transformer oils;
(f) Pollution of run-off and groundwater from herbicide treatment of power-line rights-of way, 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[145].

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. If not properly managed or treated, these pollutants 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 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 into 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 accidents) emissions of water pollutants may need to be considered in a comprehensive assessment of water pollution impacts. The likelihood is, however, that the sum of these impacts, when averaged over the net impacts of a transmission interconnection on power generation, will be rather modest.

3. 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.

E. 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.

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:

(a) Dirt, rock, and other materials removed when footings for power line towers are built, rights-of-way are cleared, access roads are constructed, or foundations for converter stations and substations are prepared;
(b) Trees and other biomass removed to clear rights-of-way (to the extent that these materials are not used for wood, fiber, or fuel);
(c) 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[146].

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.

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[147]. *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 out (that is, be dissolved in rainwater and flow out of the pile) of ash disposal sites and potentially affect ecosystems. If piles of ash are left uncovered, wind can blow smaller ash particles into the air, where their potential effects are those noted for air emissions of particulates. Disposal of ash is also an economic problem, particularly in countries where landfill space is scarce, where ash is defined as a hazardous waste, or where ash must be transported a long distance for disposal.

Scrubber sludge is an effluent of some concern for coal-fired industrial and electricity-generation equipment. A scrubber is a device in which exhaust gases 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.

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 of 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 of 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)[148].

3. Other potential fuel cycle solid waste impacts/benefits

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

(a) 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;

(b) 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 of electricity produced) than coal ash or coal mining wastes;

(c) 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;

(d) 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;

(e) Nuclear fuel extraction and preparation with its own set of wastes and impacts, including uranium mine and milling tailings, and depleted uranium metal from enrichment activities. These solid wastes must be carefully disposed of and monitored to avoid creating a radiological health hazard;

(f) Nuclear power plants also must be decommissioned at the end of their operating lives. In addition to spent fuel that must be stored indefinitely (or reprocessed, producing high- and low-level wastes that must be stored indefinitely), irradiated power plant components (especially reactor vessel components) must also be carefully dismantled and stored.

4. 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 per cent or less to 30 or more per cent. 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[149].

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 how much solid and hazardous wastes (produced during power line construction and during fuel cycle activities) are 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 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.

F. 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 of non-transmission components of the fuel cycle, far from the transmission right-of-way itself, can be among the most significant impacts in grid interconnection projects.

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 rights-of-way 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 onto 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.

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 the previous section . 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.

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.

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.

For both the interconnected case and the non-interconnected (reference) case, an accurate estimation of the net land use impacts of interconnection will require site-specific land-use requirements for:

- the transmission line
- every generating facility
- 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.

G. 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"[150]. 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 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.

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 to access for 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 present 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 rights-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.

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 downstream 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.

H. 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.

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 to 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: childhood leukemia; adult leukemia (acute lymphocytic leukemia) and other cancers; and 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[151]. 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.[152]

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

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

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.

I. 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.

1. National environmental regulations related to interconnection

As noted in Chapter III 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[153].

2. 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 additional requirements for environmental assessment and monitoring on an interconnection project and 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,[154] which 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 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."[155]

Williams notes that the World Bank Operational Manual[156] 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"[157]. Among those sections of the Manual identified as related to the potential environmental impacts of grid interconnections are:

(a) *Environmental Assessments*, for which three different main categories of requirements exist, depending on the scale of the project;
(b) *Natural Habitats*, specifying the World Bank's policy on conversion of natural habitats, and guidelines for involving local communities and others in habitat protection;
(c) *Pest Management*, describing policies preferring the use of biological and environmental pest control techniques where needed in World Bank-funded projects;
(d) *Cultural Property*, discussing policies on the conversion of lands on which important cultural resources are found, including important natural aesthetic resources;
(e) *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;
(f) *Forests*, identifying issues relating to forest conversion, which may at times be an element of the planning of an interconnection;
(g) *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" [158].

3. Types of environmental coordination needed

Several types of coordination between nations, and among 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:

(a) 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;
(b) 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;
(c) 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;

(d) Coordination in the design and construction of the power lines for the grid interconnection to ensure that the lines meet technical and environmental specifications of the countries involved. Coordination will also be needed to ensure 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;

(e) 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 electric 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.

J. SUMMARY AND CONCLUSION

1. Potential environmental benefits and costs of grid interconnection

International electric 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.

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 project, 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:

(a) 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;

(b) Make sure that any fossil-fueled power plants whose use will increase as a result of the interconnection have stringent air pollutant emission controls, discharge thermal emissions to the air or to waters where the impacts of thermal emissions are negligible, maintain 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;

(c) 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;

(d) 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;

(e) Use existing roads and rights-of-way whenever possible when new power lines or transport access is need as part of the interconnection. Where new roads and rights-of-way 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;

(f) 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 and demand-side management programs that reduce or eliminate the need for new capacity;

(g) 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) in planning the interconnection and in preparing Environmental Impact Assessments.

K. RESOURCES FOR FURTHER ANALYSIS

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, "Environmental Issues for Regional Power Systems in Northeast Asia", and papers by other authors prepared for the Third Workshop on Power Grid Interconnections in Northeast Asia, held in Vladivostok, the Russian Federation, 30 September – 3 October, 2003, and available as http://www.nautilus.org/archives/energy/grid/2003Workshop/papers.html

- World Bank, Environmental Assessment Source Book . 1999. See http://lnweb18.worldbank.org/ESSD/envext.nsf/47ByDocName/ToolsEnvironmentalAssessmentSourcebookandUpdates for access to the chapters of this document. 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 , Environmental Review Procedures for Private Sector Operations of The African Development Bank Group. 2000. Available as http://www.afdb.org/pls/portalPAGE/ADB_ADMIN_PG/DOCUMENTS/ENVIRONMENTALANDSOCIALASSESSMENTS/02%20EA%20FOR%20PRIVATE%20SECTOR%20OPERATIONS.PDF.

- 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 no longer maintained; however, the most recent version 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.

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 Agency's "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.

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[123] Much of the text in this chapter was adapted from D. F. Von Hippel and J. H. Williams, "Environmental Issues for Regional Power Systems in Northeast Asia", presented at the Third Workshop on Power Grid Interconnection in Northeast Asia, held in Vladivostok, Russian Federation, 30 September – 3 October, 2003; available as http://nautilus.org/archives/energy/grid/2003Workshop/Env_Issues_DVH_JW_final_pdf.PDF.

[124] David Von Hippel and Harry Vallack, Manual for Preparation of Emissions Inventories for Use in Modeling of Transboundary Air Pollution. Prepared as a Part of UNDP/DESA Subregional Project RAS/92/461: "Energy, Coal Combustion and Atmospheric Pollution in Northern Asia", Final Draft: 30 May, 2000. See also RAINS-Asia RAINS (Regional Air Pollution INformation and Simulation)-Asia (1999). 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.

[125] 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, "Baseline Assessment of Acid Deposition in Northeast Asia" (1997), available as http://nautilus.org/archives/papers/energy/CarmichaelESENAY1.html.pdf, and David G. Streets, "Energy and Acid Rain Projections for Northeast Asia" (1997), 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 Workshop on Power Grid Interconnection in Northeast Asia, held in Beijing, China, 14-16 May 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 it provides a great deal of detail, background, and analysis that is beyond the scope of the current paper.

[126] 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., A Guide to Environmental Analysis for Energy Planners. (Boston MA, Stockholm Environment Institute, December 1995).

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

[128] David G. Streets, "Environmental benefits of electricity grid interconnections in Northeast Asia". Energy, Vol. 8 (2003), pp. 789–807; available as http://www.nautilus/org/archives/energy/grid/2003Workshop/Z_Streets.pdf.

[129] 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 Workshop on Power Grid Interconnection in Northeast Asia, held in Vladivostok, the Russian Federation, 30 September – 3 October, 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.

[130] Relevant discussions of these issues can also be found in David Von Hippel, "Technological Alternatives to Reduce Acid Gas and Related Emissions from Energy-Sector Activities in Northeast Asia" (November 1996), available as (http://www.nautilus.org/papers/energy/dvhtech.html, from which some of the discussions in this paper are adapted; Gregory Carmichael and Richard Arndt, op.cit. and David G. Streets, "Energy and Acid Rain Projections for Northeast Asia" , op.cit.., all of which are Nautilus Institute Reports prepared for the Energy, Security and Environment in Northeast Asia (ESENA) Project.

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[131] 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^-).

[132] Peter Hayes and Lyuba Zarsky, "Acid Rain in a Regional Context", presented at the 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, held in Seoul, Korea, 13-15 June 1995; available as http://www.nautlius,org/archive/papers/enviro/acidrain.html.

[133] Jessica Hamburger, China’s Energy and Environment in the Roaring Nineties: A Policy Primer. (Washington D.C., Pacific Northwest Laboratories, June 1995. Prepared for the United States Environmental Protection Agency and the United States Department of Energy.

[134] 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.

[135] Please see Zhu Fahua, “Environmental Impacts and Benefits of Regional Power Grid Interconnections for China,” presented at the Third Workshop on Power Grid Interconnection in Northeast Asia, held 30 September – 3 October in Vladivostock, Russian Federation, and available as http://www.nautilus.org/archives/energy/grid/2003Workshop/Environmental%20Impacts_Zhu_final2.pdf.

[136] See, for example, David G. Streets, Shalini Gupta, Stephanie T. Waldhoff, Michael Q. Wang, Tami C. Bond and Bo Yiyun, “Black carbon emissions in China”, Atmospheric Environment, Vol. 35, No. 25, (September 2001), pp. 4281-4296; and Surabi Menon, James Hansen, Larissa Nazarenko, and Yunfeng Luo, “Climate Effects of Black Carbon Aerosols in China and India”, Science, Vol. 297, No. 5590, (27 September, 2002), pp.2250-2253.

[137] Surabi Menon, James Hansen, Larissa Nazarenko, and Yunfeng Luo, op.cit..

[138] Intergovernmental Panel on Climate Change, 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, 1992), p.5.

[139] 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).

[140] André Vallée and G. Jean Doucet, "Environmental Implications or International Connections: The New Arena", presented at the panel session "International High-Voltage Grids and Environmental Implications" at the 1998 IEEE Power Engineering Society Winter Meeting in Tampa, FL. IEEE Power Engineering Review, August 1998, available as http://www.geni.org/globalenergy/library/technical_-articles/transmission/ieee/power-engineering-review/international-high-voltage/grids-and/environmental-implications/index.shtml.

[141] As quoted in Patrick McCully, “Tropical Hydropower is a Significant Source of Greenhouse Gas Emissions: A response to the International Hydropower Association”, prepared for the 10th Session of the International Conference of the Parties to the United National Framework Convention on Climate Change (COP10), held in Buenos Aires, Argentina, 13 December 2004 (International Rivers Network, December 2004), available as http://www.irn.org/basics/conferences/cop10/pdf/TropicalHydro.12.08.04.pdf. Original reference is P.M. Fearnside “Greenhouse gas emissions from hydroelectric dams: Controversies provide a springboard for rethinking a supposedly ‘clean’ energy source”, Climatic Change Vol. 66, No.1-2, September 2004, pp.1-8 The authors of this report have not independently checked the assessment of high methane emissions from hydroelectric reservoirs as provided by Fearnside—it simply is noted 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.

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[142] Kenneth E. Wilkening, Leonard A. Barrie, and Marilyn Engle, "Trans-Pacific Air Pollution". Science, Vol. 290, No. 5489,(6 Oct 2000), pp. 65-67.

[143] See, for example, "Trans pacific air pollution is worse than was suspected, says new study" (27 July 2000), available at http://www.-news.ucdavis.edu/search/news_detail.lasso?id=5225.

[144] David G. Streets, "Environmental Aspects of Electricity Grid Interconnection in Northeast Asia", op.cit. 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 VI.K for sources for this topic.

[145] The compaction of soils due to transmission line construction was noted to have an impact on the hydrology of wetland soils in Public Service Commission of Wisconsin, PSC Overview Series, Environmental Impacts of Electric Transmission Lines., available as http://psc.wi.gov/consumer/brochures/electric/6010.pdf.

[146] 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, ToxFAQs™ for Polychlorinated Biphenyls (PCBs), (February 2001); available as http://www.atsdr.cdc.gov/tfacts17.html.

[147]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.

[148] Jungmin Kang, "Environmental Impacts and Benefits of Regional Power Grid Interconnections for the Republic of Korea: Potential Impacts on Nuclear Power Generation and Nuclear Waste Production", presented at the Third Workshop on Power Grid Interconnection in Northeast Asia, held in Vladivostock, Russian Federation, 30 September – 3 October, 2003; available as http://www.nautilus.org/archives/energy/grid/2003Workshop/Jungmin_KANG_final.pdf. This paper discusses in more detail nuclear power and nuclear waste issues associated with grid interconnections involving the ROK.

[149] An example of a set of estimates of nuclear material "emission factors", originally derived from several sources, can be found in David Von Hippel and Peter Hayes, "Two Scenarios of Nuclear Power and Nuclear Waste Production in Northeast Asia", prepared for the Yonsei University Department of Political Science (Nautilus Institute, October 1997). A version of this document can be found at http://www.nautilus.org/archives/papers/energy/dvh_hayesNukeScenarios.pdf.

[150] 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.

[151] 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); available as http://www.niehs.nih.gov/emfrapid/html/WGReport/WorkingGroup.html

[152] John Harte et al, Toxics A to Z: A Guide to Everyday Pollution Hazards, Berkeley: U.C. Press, 1991.

[153] Four papers by authors from Northeast Asia (prepared for the Third Workshop on Power Grid Interconnection in Northeast Asia, held in Vladivostok, Russia, 30 September – 3 October 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" by Alexander S. Sheingauz. 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.

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[154] James H. Williams, “International Best Practices for Assessing and Reducing the Environmental Impacts of High-Voltage Transmission Lines”, presented at the Third Workshop on Power Grid Interconnection in Northeast Asia, held in Vladivostok, Russia, 30 September -3 October 2003; available as http://www.nautilus.org/archives/energy/grid/2003Workshop/Env_Best_Practices_Williams_final.pdf.

[155] Ibid.

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

[157] James H. Williams, “International Best Practices,” op. cit.

[158] World Bank, Environmental Assessment Source Book (Washington, D.C., World Bank, 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”).

VII. INTERNATIONAL GRID INTERCONNECTIONS AND ENERGY SECURITY

A. THE CONCEPT OF ENERGY SECURITY

One justification often noted for international electric grid interconnection is that they can, depending on how they are configured, improve energy security in the interconnected countries. “Energy Security” has typically, to those involved in making energy policy, meant mostly securing access to oil and other fossil fuels. With increasingly global, diverse energy markets, however, old energy security rationales are less important, and other issues, including climate change, other environmental, economic, social, and political considerations are becoming increasingly important. As a consequence, a more comprehensive operating definition of “Energy Security” is needed, along with a workable analytical framework for assessing which of many possible energy paths or scenarios (including those both with and without grid interconnections or similar international projects) yield greater energy security for the areas considered[159].

Many of the existing definitions of energy security begin, and usually end, with a focus on maintaining supplies of energy, particularly oil. This focus has as its cornerstones reducing vulnerability to foreign threats or pressures, preventing a supply crisis from occurring, and minimizing the economic and military impact of a supply crisis once it has occurred. National energy policies today are being challenged on multiple fronts. The substance of these challenges needs to be incorporated into a new, broader concept of energy security. Current national and international energy policies have been facing many new challenges and have at their disposal new tools that need to be considered as key components of new energy security concepts. At least five key components (environment, technology, demand side management, social and cultural factors, and post-Cold War international relations) are central additions to the traditional supply-side point of view.

Considering the addition of these concepts, a new definition of Energy Security is as follows:

A nation-state is energy secure to the degree that fuel and energy services are available to ensure: a) survival of the nation, b) protection of national welfare, and c) minimization of risks associated with supply and use of fuel and energy services. The six dimensions of energy security include **energy supply**, **economic**, **technological**, **environmental**, **social and cultural**, and **military/security** dimensions. Energy policies must address the domestic and international (regional and global) implications of each of these dimensions.

What distinguishes this energy security definition is its emphasis on the need to consider extra-territorial implications of the provision of energy and energy services, while recognizing the complexity of actualizing (and measuring) national energy security. The definition is also designed to include emerging concepts of environmental security, which include the effects of the state of the environment on human security and military security, and the effects of security institutions on the environment and on prospects for international environmental cooperation.

B. DIMENSIONS OF ENERGY SECURITY

Some of the possible dimensions, measures, and attributes of energy security, as broadly defined above, are summarized in Table VII.1. Grid interconnections will or can affect virtually any or all of these dimensions, as the discussion in the previous chapters in this report has shown. As a consequence, the identification of the overall energy security benefits of any given interconnection is a complex exercise, but one that typically begins with a comparison of alternatives for providing energy services with and without a proposed interconnection project.

Table VII.1: Dimensions and attributes of energy security

Dimension of Energy Security	Attributes	Interpretation
Energy Supply	Total Primary Energy	Higher = indicator of other impacts
	Fraction of Primary Energy as Imports	Lower = preferred
	Diversification Index (by fuel type, primary energy)	Lower index value preferred
	Diversification Index (by supplier, key fuel types)	Lower index value preferred
	Stocks as a fraction of imports (key fuels)	Higher = greater resilience to supply interruption
Economic	Total Energy System Internal Costs	Lower = preferred
	Total Fuel Costs	Lower = preferred
	Import Fuel Costs	Lower = preferred
	Economic Impact of Fuel Price Increase (as fraction of GNP)	Lower = preferred
Technological	Diversification Indices for key industries (such as power generation) by technology type	Lower = preferred
	Diversity of R&D Spending	Qualitative—Higher preferred
	Reliance on Proven Technologies	Qualitative—Higher preferred
	Technological Adaptability	Qualitative—Higher preferred

Table VII.1 (continued): Dimensions and attributes of energy security

Dimension of Energy Security	Attributes	Interpretation
Environmental	GHG emissions (tonnes CO_2, CH_4)	Lower = preferred
	Acid gas emissions (tonnes SOx, NOx)	Lower = preferred
	Local Air Pollutants (tonnes particulates, hydrocarbons)	Lower = preferred
	Other air and water pollutants (including marine oil pollution)	Lower = preferred
	Solid Wastes (tonnes bottom ash, fly ash, scrubber sludge)	Lower = preferred (or at best neutral, with safe re-use)
	Nuclear waste (tonnes or Curies, by type)	Lower = preferred, but qualitative component for waste isolation scheme
	Ecosystem and Aesthetic Impacts	Largely Qualitative—Lower preferred
	Exposure to Environmental Risk	Qualitative—Lower preferred
Social and Cultural	Exposure to Risk of Social or Cultural Conflict over energy systems	Qualitative—Lower preferred
Military/Security	Exposure to Military/Security Risks	Qualitative—Lower preferred
	Relative level of spending on energy-related security arrangements	Lower = preferred

C. POTENTIAL IMPACTS OF GRID INTERCONNECTIONS ON ENERGY SECURITY

International electric grid interconnections can have impacts on (that is, provide costs and/or benefits in) each of the dimensions of energy security described in Table VII.1, and probably many additional dimensions as well. Table VII.2 provides just a few examples of how grid interconnections might provide benefits, and incur costs or risks, in each of the dimensions described. These examples are neither exhaustive nor necessarily likely to occur in any given interconnection project. What is clear, as was noted above, is that the impacts of a grid interconnection on energy security may be quite complex, and that any given interconnection project, evaluated from a particular national point of view, will require trade-offs between the different dimensions of energy security. Further, a review of all of these dimensions is necessary to determine whether a nation and its people are likely to be more energy secure with or without the grid interconnection project.

Table VII.2: Examples of potential energy security benefits and costs of grid interconnections

Dimension of Energy Security	**Interconnection Benefits**	**Interconnection Costs/Risks**
Energy Supply	Improved electricity supply	Higher energy imports and increased import dependence
	Diversification of energy supply sources	Dependence on reliability in the interconnected system
	Diversification in fuel imports	Obligation to export resources
	Improved reliability of electricity supply	
Economic	Lower costs of fuel, capital expenditures for importing country (or both partners, in some exchanges)	Additional costs of infrastructure for interconnection
	Earnings from power sales through interconnection (foreign exchange)	Additional costs for generation and other infrastructure in exporting nation
	Indirect economic benefits of less expensive, more reliable electricity (education, jobs, health care, re-spending of cost savings)	Foreign exchange outlays and indebtedness for infrastructure investments
	Cost savings through substitution of electricity for other fuels (lamp oil, batteries)	Exposure to energy price volatility on international markets and/or to terms of “locked-in” contracts
	Economic interdependence	Economic interdependence
Technological	Improvement in power quality	Exposure to risk from poor power quality in interconnected nations
	Exposure to new technologies that can be replicated to improve power system	Exposure to risk from use of new technologies
	Reliance on proven technologies for generation and transmission	Risk of being obligated to continue use of an older technology as newer, cheaper, more flexible technologies become available (lack of future adaptability)

Table VII.2 (continued): Examples of potential energy security benefits and costs of grid interconnections

Dimension of Energy Security	Interconnection Benefits	Interconnection Costs/Risks
Environmental	Reduced emissions of air pollutants of local, regional, and/or global significance	Increased emissions of air pollutants of local, regional, and/or global significance Lower = preferred
	Reduced water pollution, solid wastes due to avoided generation, fuel storage, other fuel cycle activities	Increased water pollution, solid wastes due to additional generation, fuel storage, other fuel cycle activities, construction impacts
	Reduced ecosystem and aesthetic impacts through avoided construction of new generation	Increased ecosystem and aesthetic impacts through construction of power lines, new generation plants, construction/operation of facilities in previously isolated areas
	Reduced exposure to environmental risk through avoidance of need to build new generation with uncertain environmental impacts	Increased exposure to environmental risk through reliance on big projects with uncertain, potentially diverse environmental impacts
Social and Cultural	Increased availability of medical care, education, employment opportunities through extended and/or more reliable and/or less expensive electricity supplies	Risk of social conflict if benefits of interconnection project are not shared appropriately, or if graft or other preference is perceived
	Reduced exposure to risk of social or cultural conflict by bringing cultures together to share power resources	Increased risk of internal social and cultural conflict as isolated populations are brought into contact with construction teams and others associated with the interconnection project
	Improvement of social capacity to participate in complex decision-making	Isolation of populations from traditionally-used resources; “boomtown” impacts
Military/Security	Reduced exposure to international military/security risks by increasing political and economic dependence between nations	Increased exposure to international military/security risk by tying economy to inputs from another nation, thus leaving both nations vulnerable to each others’ internal conflicts
	Reduced need for internal security due to social benefits of improved electricity supply (reduced unemployment, greater education)	Increased need for spending on energy-related security arrangements, such as on securing power lines

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[159] Some of the text for this Chapter was derived from D. Von Hippel, “Energy Security Analysis, A New Framework”, reCOMMEND, “A Newsletter of the Community for Energy, Environment, and Development”, Volume 1, Number 2, (December, 2004), pp. 4-7; available as http://forums.seib.org/leap/reCOMMEND/reCommend2.pdf. The summary provided here and included in the reCOMMEND article was based on work done as a part of the Nautilus Institute‘s “Pacific Asia Regional Energy Security” project (PARES), which had as its goals to propose a consensus definition of "energy security", develop an analytical framework to address energy security dimensions of choices in energy sector development, prepare illustrative medium-range energy "paths" for Japan (1995 to 2020), evaluate the energy paths against a suite of energy security criteria using the framework, and review the results for applicability to other countries of the region. Available from Nautilus Institute at http://nautilus.org/archives/pares/PARES_Synthesis_Report.PDF.

VIII. CONCLUSIONS AND RECOMMENDATIONS FOR FOLLOW-UP

A. REVIEW OF MAJOR ISSUES ASSOCIATED WITH INTERNATIONAL GRID INTERCONNECTION

International electric grid interconnections, particularly those spanning large distances, carrying large amounts of power, and/or involving several countries, are complex undertakings, with varied, varying, and potentially diverse issues, costs, and benefits. These issues, costs, and benefits are multi-disciplinary, almost always having technical, economic, legal, political, social, and environmental aspects that must be considered. Some of the key elements of each of these aspects are reviewed briefly below.

1. Technical aspects of grid interconnection

Among the basic technical issues that must be addressed early in the planning process for a grid interconnection are whether interconnected systems operate synchronously (at the same frequency) or asynchronously, what the magnitudes and directions of the anticipated power flows are to be, what physical distance and terrain will be spanned by the interconnection, and what the key technical and operating differences are among the systems to be interconnected.

For AC interconnections, key design and operating issues relate to the constraints on transmission capacity (both of the interconnection and of the grids that it connects) which include thermal limits, stability limits, and voltage regulation. Where there are liberalized electricity markets, these constraints may become more severe as systems are operated closer to capacity in order to maximize net revenues. HVDC and other transmission options may be considered as alternatives or complements to traditional transmission upgrades in interconnections. Simulation software is an essential tool for planning and operating an interconnection. For modeling to be effective, however, extensive technical data must first be gathered and shared between systems, and personnel must be trained. Grid interconnections require a careful calculation of costs, benefits, and risks. Technical planning of a grid interconnection should be coordinated with economic, organizational, legal, and political aspects of a potential interconnection project from the outset of project consideration.

2. Economic Aspects of Grid Interconnection

Grid interconnections may offer both direct and indirect economic and financial costs and benefits. Examples of direct economic benefits to the electricity generation systems of one or all of the nations participating in the interconnection are “avoided costs”, that is, direct costs that are avoided by the use of the interconnection, including costs for purchase and/or production of fuels used in electricity generation, capital costs of generation facilities, operating costs of generating facilities, and capital and operating costs for any transmission facilities avoided by the interconnection. Another direct economic and financial benefit of an interconnection to a country is income from power sales, with payments for power made in hard currencies of particular importance to many developing economies. Direct costs related to the interconnection include the costs of fuels used to generate electricity for export (and of running the facilities needed to supply fuels), the capital and operating costs of generation facilities, and the costs of building and running the interconnection itself, as well as the costs of purchasing power.

The indirect costs and benefits of an interconnection potentially include the stimulation of national and local economies through employment of labor needed for facilities construction, and to a lesser extent, of the labor needed to operate the interconnection (and associated power plants) on an ongoing basis. Where significant amounts of short-term construction labor are needed, there is the risk of non-sustainable economic development in local areas—the "boomtown" effect. Other potential indirect economic benefits of an interconnection include the impacts of improved power supplies in fostering development of local industry and improvements in education and health care, as well as the "re-spending" effect in which electricity price reductions leave households with more disposable income available for other consumption, for savings, and for investment in productive activities. Depending on how the institution selling the power from the interconnection is configured, an interconnection may spur markets for power generation in one or more of the interconnected nations, further reducing electricity prices.

Pricing arrangements are needed to specify what the buyer(s) and seller(s) will pay and receive for electricity (electric energy and power) and electric system services (capacity and ancillary electric system services) provided through the interconnection. Prices can be specified based on production costs or avoided costs, or through negotiation, with market-based pricing a possibility where enough buyers and sellers exist to provide for structured, fair competition.

3. Legal Aspects of Grid Interconnection

International electric grid interconnections, except perhaps in their very simplest forms, can be very complex legal undertakings, involving a variety of national, sub-national, and even international parties to the agreements required for planning, building, and operating power lines used to buy and sell electricity across borders. As such, binding legal agreements between countries (and between the countries and the outside lenders, if any, providing project financing), as well as the negotiation processes that produce the agreements, must be transparent and enforceable. This requires national legal capacity to draft, review, enforce, adhere to, and in the event of a disagreement, adjudicate contract issues.

Some of the key issues that must be addressed in setting up a legal framework for international electric grid interconnections include:

(a) Power purchase and pricing agreements, including agreements on the currency of payment, the escalation and/or indexing of prices to prices of other energy commodities over time, and penalties if sales or purchase minimums are not met;

(b) Agreements on siting of power lines and related infrastructure, such as routes between generating plants and consuming grids, and placement of substations and interconverter (for AC-DC-AC systems) stations;

(c) Agreements on power line operation, including deciding upon or constituting a joint authority to operate the interconnection, and agreeing on how the power line operator will be governed or overseen by both parties. Agreements on power line operation will also include agreements on how the interconnection right-of-way is to be maintained;

(d) Agreements on power line security, including agreements on which parties will be liable in the event of different types of incidents resulting in power line damage;

(e) Agreements on the environmental performance of the interconnection, potentially including environmental standards to be met during construction of the line, and environmental and safety (including fire safety) standards to be met during line operation;

(f) Agreements on liability for power line failure, including damages to third parties caused by power line failure;

(g) Agreements for the orderly, fair, and open selection of contractors to build and/or finance and/or operate and maintain interconnection infrastructure, including agreements on how such contractors are to be overseen by parties to the project.

4. Political aspects of grid interconnection

International electric grid interconnections may bring political benefits to the interconnected countries, including increased experience and political comfort with international cooperation, more reasons to avoid conflict with neighbors, increased democratization (depending, in part, on how the interconnection is designed and administered), and an increase in internal political stability. On the other hand, in some cases, the existence of an interconnection may be used as an excuse for internal political oppression, may give one of the interconnected countries more political and economic leverage over another, may entangle countries in each others' internal affairs, may provide potential for political graft, and may entail significant political costs for power line protection.

Designing, constructing, and operating power line interconnections require political cooperation both between and within countries on a number of fronts, including:

(a) Agreements in principle as to sharing power resources—political agreement between the two governments that such sharing of resources would be mutually beneficial;
(b) Agreements on moving forward with the interconnection project, including agreements on contractor selection, power line routing, and other major decisions;
(c) Agreements as to how interconnection project contractors will be paid, and by whom;
(d) Agreements as to how the benefits and costs of the project will be shared between and within nations;
(e) Agreements as to how the interconnection infrastructure will be operated and secured, including agreement on the governance of the interconnection operator;
(f) Agreements as to the sharing of information necessary to plan, operate and protect the interconnection.

5. Social Aspects of Grid Interconnection

International grid interconnection projects may yield significant social benefits to some or many groups in the nations participating in the projects, for example:

(a) An international interconnection may help to provide better power quality, more reliable power, and more widespread availability of electricity to communities. Greater availability of affordable electricity can provide more opportunities for education, improvements in health care, development of employment opportunities, and reduction of difficult and labor-intensive tasks, all of which can contribute to sustainable development;
(b) The income to power-exporting countries from an interconnection project may have many positive social impacts, if carefully and equitably distributed, particularly when spent toward social development goals such as education, health care, housing, agricultural improvement, and creation of employment opportunities;
(c) Successful operation of a grid interconnection may provide the experience and incentive for interconnected countries to embark on additional cooperative activities, including cultural exchanges and additional trade, resulting in improved relations between the countries.

Grid interconnection also may yield social costs and/or liabilities, for example:

(a) The presence of a power line or other types of infrastructure used in grid interconnections may partially or totally physically separate local groups from the water, land, forest, agricultural, social and economic (local towns and markets), and other resources that they use regularly;

(b) The process of construction of interconnection infrastructure may bring in unwanted outside influences, causing social problems in formerly isolated local populations ranging from alcoholism to violence;

(c) For electricity exporting countries, the construction and operation of power plants built to feed an interconnection, and of the fuel supply infrastructure that feeds the power plants, may have significant social impacts. Displacement of populations by new facilities (particularly hydro facilities) can be considerable and can lead to social problems such as out-migration from rural areas to the margins of cities, under-employment, and dislocation from ancestral lands;

(d) For electricity importing countries, use of electricity provided via an interconnection from a neighboring country can reduce the incentive to use local resources, can increase the vulnerability of communities to cuts in power supply that are outside of the control of the community and the nation, and can reduce the preparedness of the community to deal with electricity shortages.

6. Environmental aspects of grid interconnection

International electric 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, through its impact on electricity generation and/or the use of other fuels in one or more of the nations participating in the project. Net environmental impacts in each of these categories, however, 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.

B. KEY ATTRIBUTES OF SITUATIONS WITH GRID INTERCONNECTION THAT LEAD TO THE MUTUAL ADVANTAGE OF TRADING PARTIES

From the technical and economic perspectives, groups of countries where at least one partner has significant untapped, and possibly remote energy resources that can be converted to electricity, and/or where the timing of peak demand is significantly different between countries, and/or where strong load growth is expected, will make the best partners in an interconnection project. The sharing of technical grid standards, including similar nominal and actual operating parameters, is another key attribute for potential interconnection partners.

From a legal perspective, countries with existing frameworks for contract enforcement, significant human capacity in the legal and judicial professions, effective and consistent regulatory structures, stable political systems, and experience in being a party to international legal agreements will have a smoother path to success in interconnection projects.

From a policy perspective, countries sharing the political will to cooperate on a grid interconnection are most likely to reach the legal agreements necessary to run a grid interconnection smoothly and in a timely manner, and indeed most likely to attempt to enter into such arrangements in the first place. Countries sharing a culture of regional or international cooperation, having a culture of active long-term planning and clear energy policy goals, having shown a previous willingness and ability to ratify and adhere to international agreements, sharing a history of cross-border trade on key commodities, and having common membership in strong regional organizations are most likely to be able to reach political agreement on grid interconnections.

From a social perspective, countries where there is a clear commitment to allowing different social groups a voice in the planning of an interconnection project, and to making sure that the benefits (and costs) of the interconnection project are both fairly distributed and well-anticipated, are likely to benefit most from an interconnection, and find a smoother path to project implementation and operation.

From an environmental perspective, countries where the new resources that an interconnection draws upon are significantly cleaner, environmentally, than the energy resources displaced by the output of the interconnection, will benefit the most. Where interconnection infrastructure can be installed in existing rights–of-way and on existing power plant sites, environmental damage due to changing land uses can be minimized.

C. SUMMARY OF KEY STRATEGIES FOR MAXIMIZING BENEFITS AND MINIMIZING THE COSTS OF GRID INTERCONNECTIONS

Given the potential benefits, costs, national attributes favoring agreements, and barriers to cooperation in each of the six main issue areas covered in this report, some of the key potential overall strategies for reaching the necessary agreements to implement an interconnection project include:

(a) Ensure the *fair distribution of economic, social, and other benefits and costs* among the nations involved in an interconnection, as well as among the groups within nations that are “stakeholders” in the interconnection. This is an important element in ensuring that the net benefits of an interconnection are maximized, and that the political, social, and other costs are kept low;

(b) Ensure that the *direct costs and avoided costs of an interconnection are specified as accurately as possible*, preferably within the context of comprehensive long-term power system (and overall energy sector) planning. This means that analyses of the economics of power trade across all of the nations involved in an interconnection project (or set of projects) need to be part of both short- and long-term electricity and overall energy-sector planning by the project participants;

(c) *Emphasize transparency* in all negotiations related to grid interconnections, including allowing all stakeholders access to all relevant materials;

(d) Include *all* (or at least all major) *potentially affected parties in the early stages of project formulation*, and continue to solicit the input of all parties on key decisions throughout the project;

(e) Establish clear needs and protocols *for collecting and distributing quantitative data and other information* needed for project design, as well as for the accurate estimation of project costs and benefits;

(f) Establish *clear legal and administrative authorities* over all aspects of the design, construction, and operation of the grid interconnection. In some cases this may require building legal and regulatory capacity within the participating countries;

(g) Work *with and through international and regional institutions*, including international financial institutions, to help smooth the path to political agreement, as well as to assist in providing the capacity for all groups to contribute meaningfully to decisions related to the interconnection;

(h) Locate new power lines in *existing transmission or transport corridors* as much as possible;

(i) Continue *planning and assessment studies even after the grid integration project is completed*, and avoid the temptation to cease assessment studies when the project is completed;

(j) Implement *capacity building* to allow different social stakeholder groups to meaningfully participate in investigating and deciding upon grid interconnection options, and in planning for grid interconnection construction and operation;

(k) Undertake a thorough *estimate of the significant environmental costs and benefits* that will flow from a grid interconnection. This will require 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.

In a presentation at a USAID SARI/Energy Semi Annual Meeting in South Asia, Vladislav Vucetic of the World Bank lists a number of strategies for regional energy and grid cooperation, in the context of a “way forward” for the development of interconnection projects. These strategies are summarized in Figure VIII.1. Many of the approaches outlined above are explicit or implicit in the strategies recommended by Vucetic.

The way forward

- **Increasing bilateral trade ("bottom up")**
  - Pursue simpler deals first
  - Get the private sector involved (in partnership with the public sector)
- **Strengthening physical infrastructure (in conjunction with specific trading deals and investment projects): gradually constructing regional electricity (and gas) transmission network, starting from bilateral interconnections**
- **Getting the broad framework right to open up longer term trading and investment potential ("top down"):**
  - Analysis of regional energy trade economics
  - Addressing institutional, regulatory and policy issues
  - Addressing technical issues: parallel operation of electrical grids
  - Developing commercial framework for trading: framework trading agreements, model power purchase agreements
  - Addressing investment issues: investment protection, regional investment planning, riparian rights, right of way for electricity transmission lines and gas pipelines, environmental and social concerns, etc.
- **Using the existing (or complementing) regional forums for multi-country discussions and coordination (SAARC, ECO?)**

Figure VIII.1: "The Way Forward", strategies for cooperation on energy interconnections[160]

D. FULL AND CONSISTENT CONSIDERATION OF INTERCONNECTION OPPORTUNITIES REQUIRED IN INTEGRATED AND LONG-TERM ELECTRICITY SYSTEM PLANNING

The need to embed the consideration of interconnection projects into the broader consideration of electricity system planning, and even overall energy sector planning, was noted above, but deserves special additional mention. All costs and benefits of a long-term project like an interconnection (whether they are economic, social, political, or environmental) must be measured relative to other means of providing the same energy services. As technology progresses, the number of other means of providing those energy services is growing rapidly, including not only construction of new large power plants, but on-site renewable or fossil-fueled generation for businesses and homes, energy efficiency improvements, fuel switching, and even alternative social organizations (though this is very difficult to include in planning).

An interconnection project of significant size represents a considerable investment, not only in economic terms but often also in political and social terms, as well as being a magnet for available human capacity. Before completing such an investment, it is critical that the societies involved examine, to the best of their ability and in multiple dimensions[161], alternatives for providing energy services for sustainable development that include, but go beyond, grid interconnection. The ability to do such studies (and indeed, to meaningfully do any of the studies necessary for grid interconnection itself) depend on the availability of human analytical and planning capacity, the collection and organization (and sharing) of robust sets of data describing current conditions and recent trends (including data on energy use, topography, demographics, and the status of the environment, just to name a few), the coordination of plans between sectors, and, most importantly, the cooperation and consistent, ongoing support and encouragement of the governments that the studies will serve. It is important to stress again here that the term "planning studies" does not mean determining a detailed plan for the long-term future of an energy sector, if indeed that were possible (particularly in this age of markets). These studies are rather designed to show which energy sector strategies are clearly viable, and which are clearly not, relative to other alternatives that appear (at least at present) reasonable. The planning studies, therefore, point out an overall direction, to be updated regularly, in which policy can guide energy sector and other actors as the future unfolds.

E. RECOMMENDATIONS

There are many areas of activity related to grid interconnections where United Nations agencies and other international organizations could very usefully provide support and structure to assist in evaluating and, more importantly, in developing the human capacity to evaluate international grid interconnection projects. These include (but are by no means limited to) the items discussed below.

1. Training

Evaluating the many complexities associated with grid interconnection will require people, preferably local to the region for which the interconnection is considered, who are trained in a number of both general and specific professional areas. These areas include:

- Electricity transmission engineering and power flow modeling
- Power plant engineering
- Civil engineering
- Utility finance and project financial analysis, including tariff setting
- Utility (transmission, power plant, and other) project management
- Utility law
- Utility metering, collections, and accounting systems
- Contracts enforcement
- Power marketing
- Utility regulation
- Negotiation and arbitration (including skills for convening and management of stakeholder groups)
- Information systems and database development
- Energy planning and electricity systems planning
- Policy development and facilitation of political communications
- Energy, environmental, and social data collection and analysis
- Social impacts assessment

- Environmental modeling
- Environmental sampling and damage assessment

These daunting training tasks often need not (and generally should not) start “from the ground up” (building whole new programs). Rather, they should build on existing training resources in each region, including those in local colleges and universities. E.A.K. Kalitsi summarized this approach as “Identify centers of excellence within each sub region, which serve as training centers for sharing of experience.”[162]

2. Compilation of Information

The evaluation of grid interconnection requires many types of information. In many countries, these data are disorganized, dispersed, and closely held for personal, organizational, economic or political reasons, or simply (and most often) not available at all. United Nations agencies and other international organizations could provide support for data collection and compilation in a number of areas, including:

(a) Technical parameters of national transmission systems, including an inventory of transmission and power plant infrastructure;
(b) Power loads and flows at all relevant points in national and regional transmission systems (as needed for power flow modeling);
(c) The status of national and regional systems needed to support interconnections, such as regulatory, financial, and legal systems;
(d) Electricity load forecasts (if they exist);
(e) Energy sector development plans (if they exist);
(f) Demographic and social features of areas potentially affected by an interconnection (including collection of information on local needs for energy services);
(g) Hydrologic and other data related to water resources;
(h) Environmental data (existing pollutant emissions and impacts, for example);
(i) Data on the costs and performance of new technologies (including power plant, power transmission and distribution, demand-side energy-efficiency, renewable energy, and pollution control devices).

3. Sponsor Analytical Activities

In many cases where the investigations of interconnections are desirable, the combination of financial resources, capability, and political trust in a convening party may not exist to underwrite necessary pre-project analysis (especially analysis open to all stakeholder parties) unless regional or international organizations act as sponsors. Some of the analytical activities that the United Nations and other multilateral agencies might usefully sponsor include:

(a) Power flow modeling of non-connected and interconnected systems;
(b) Analysis of market systems for power trading;
(c) Economic impact analysis (pre-, during, and post-project);
(d) Electricity sector planning, and overall energy planning, including forecasts of demand for electricity and for energy services;
(e) Environmental assessment and impact analysis (pre-, during, and post-project);
(f) Social impact assessment (pre-, during, and post-project).

4. Support for Engagement

United Nations agencies and other international organizations have traditionally provided support for events and processes where counterparts from different countries, and often regions, can meet to discuss matters of shared concern in a neutral setting. In addition, the United Nations and other organizations can help to support the engagement of sub-national stakeholders in the interconnection planning process, including stakeholders who otherwise might not have a strong voice in the process. A number of both of these types of support opportunities exist, a few of which include:

(a) Regional study groups on the technical, economic, legal/regulatory, political/social, and environmental aspects of interconnections to serve a particular area;
(b) Inclusive national and regional stakeholder meetings regarding interconnection prospects in general, and/or specific interconnection options in particular;
(c) Meetings of those involved in interconnection projects in different regions of the world where participants can share experiences and learn from each other;
(d) Support (including training, expert analytical and tactical support, and project support) for the intervention of stakeholder groups (such as local indigenous groups, women's groups, environmental organizations, and other) in interconnection planning processes.

Although many of the processes associated with planning and developing an international electric grid interconnection will, appropriately, be sponsored by the governments, utilities, and other key beneficiaries of the interconnection project, there remain many initiatives that will likely go unfunded and undone without support from UN or other outside agencies. Without the types of support for engagement noted above, it is likely that the full scope of project costs (and benefits) will remain under-evaluated, and that many stakeholder groups will receive insufficient information to protect and advance their rights.

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[160] Vladislav Vucetic (2004), World Bank's South Asia Energy Program. Presentation at the USAID SARI/Energy Semi Annual Meeting, New Delhi, October 12-13, available as 2004http://sari-energy.org/DynamicPPTShow/PPTDownloads/PPT103OCT04.zip. Figure shown is slide 24. Vucetic's presentation also provides good summaries of many other topics relevant to international grid interconnections, including market arrangements, benefits of energy trade, barriers to trade, risks of energy trade/mitigation measures to reduce risks, and the potential roles of international agencies in interconnection projects.

[161] Perhaps, for example, using a method like the energy security analysis methodology outlined in Chapter VII of this report.

[162] E.A.K. Kalitsi , "Problems And Prospects for Hydropower Development in Africa", presented at the Workshop for African Energy Experts on Operationalizing the NGPAD Energy Initiative, held in Dakar, Senegal, 2 – 4 June 2003, p.17; available as http://www.un.org/esa/sustdev/sdissues/energy/op/nepadkalitsi.pdf.

GLOSSARY[163]

Abatement: Reducing the degree or intensity of, or eliminating, pollution.

Aggregator: An entity responsible for planning, scheduling, accounting, billing, and settlement of energy deliveries from the aggregator's portfolio of sellers and/or buyers. Aggregators seek to bring together customers or generators so they can buy or sell power in bulk, making a profit on the transaction.

Alternating current (AC): Electric current which alternates between positive and negative polarity with respect to ground.

Ampere (or Amp, A): A measure of electrical current.

Ancillary services: Services by generators and/or by the operators of the interconnection to the power grid or grids, including services (such as spinning reserve, short-term regulation of grid stability, and electricity for "black start" of power plants) that allow for the smooth operation of grid systems and maintenance of power quality.

Apparent power: The complex sum of real and reactive power, measured in volt-amperes (VA).

Autoproducer: Autoproducers are industries or other (typically larger) electricity users that generate electricity and/or heat, wholly or partly for their own use, as an activity that supports their primary activity. Autoproducers may be privately or publicly owned.

Availability factor: The ratio of the time a generating facility is available (that is, fueled and ready to operate) to produce electricity at its rated capacity to the total amount of time in the period being measured (for example, one year/8760 hours).

Avoided costs: The total economic costs (consisting of the capital and operating costs to provide generation capacity and fuel, transmission, storage, distribution, and customer service) to serve end-use energy requirements using a given set of resources. These costs are referred to as "avoided" when an alternative set of resources is used to serve requirements. Avoided costs must be determined to assess the cost-effectiveness of potential supply-side and demand-side resources.

Base load: The minimum average electric load on a given system over a given period of time.

Base load generation: Those generating facilities within a utility system that are operated to the greatest extent possible to maximize system mechanical and thermal efficiency and minimize system operating costs.

Base load unit/station: Units or plants which are designed for nearly continuous operation at or near full capacity to provide all or part of the base load. An electric generation station normally operated to meet all, or part, of the minimum load demand of a power company's system over a given amount of time.

British Thermal Unit (Btu): A measure of energy (most often applied to heat) equal to 1055 Joules.

Carbon dioxide (CO_2): A colorless, odorless, nonpoisonous gas that results from fossil fuel combustion and is normally a part of the ambient air.

Carbon monoxide (CO): A colorless, odorless, poisonous gas produced by incomplete fossil fuel combustion.

Carcinogen: Any substance that can cause or contribute to the production of cancer.

Clean Development Mechanisms (CDMs): Flexible mechanisms of the Kyoto Protocol (see Kyoto Protocol). CDMs enable industrialized countries to finance emissions-avoiding projects in developing countries and receive credit for doing so.

Capacitance: The ability of a system to store an electric charge; a physical phenomenon that can impede the flow of current.

Capacity: The maximum quantity of electrical output for which a supply system or component is rated.

Capacity expansion plan: The schedule of power supply investments that is planned in order to meet forecasted future electricity demand.

Capacity factor: The ratio of the average output of an electric power generating unit for a period of time to the capacity rating of the unit during that period. A capacity factor of 50 per cent means that, for example, a power plant produces on average half of the electricity that it could have produced if operated continuously at its full capacity rating.

Capacity rating: A measure of the electric power that a piece of equipment can be expected to produce or use if used fully under normal (non-emergency) conditions.

Capacity value: The contribution of a supply resource to the maximum capacity of an electric system. Capacity value is a measure of the reliability and predictability of a resource.

Capital recovery rate: This is the rate of return paid on the debt plus the rate of return paid on the principal.

Cogeneration (or Combined heat and power—CHP): The generation of electricity together with the recovery of heat as a usable by-product, or the production of electricity as a by-product of the production of heat. Cogeneration, or CHP, involves the recovery of heat or primary energy that would otherwise be wasted.

Coincident demand: The rate of electricity demand of a customer or group of customers at the time of an electric system's total peak demand.

Coincident peak: Customer demand at the time of electric system peak demand.

Combined cycle: A two-stage electricity generation process. In a common type of combined-cycle configuration, in the first stage electricity is generated by a gas turbine. The waste heat from the gas turbine is then used with a steam turbine to generate additional power. Gas-fired combined-cycle power plants are becoming increasingly popular, inexpensive, and efficient alternatives for intermediate and base-load power generation when affordable gas is available.

Combined heat and power (CHP): See cogeneration.

Competitive bidding: The process of acquiring supply-side or demand-side resources from private or public-sector companies or organizations by issuing "bid documents" or "requests for proposals", distributing these documents to potential suppliers, reviewing proposals and bids received based on a set of defined criteria, and selecting the best proposal or proposals for implementation (or further study).

Conductance: The ability of an object, such as an electric wire, to allow electric currents to flow.

Control area: An electric system or systems, bounded by interconnection metering and telemetry, capable of controlling generation to maintain its interchange schedule with other control areas and contributing to frequency regulation of the interconnection.

Current: The flow rate of electric charge, measured in amperes (A) or kilo-amperes (kA).

Demand forecast: Projected future demand for electric power. A demand (or load) forecast may be short-term (for example, 15 minutes ahead) for system operation purposes, medium to long-term (5 to 20 years) for generation planning purposes, or for any range in between. Load forecasts may include projections of peak demand (kW), energy (kWh), reactive power (kVAR), and/or load profile. Forecasts may be made of total system load, transmission load, substation/feeder load, individual customers' loads, or appliance loads.

Demand-side management (DSM): The implementation of one or more demand-side management programs. Demand-side management denotes the increases in energy efficiency, reduced demand, improved load factors, or improved customer power factor resulting from hardware, equipment, devices, or practices that are installed or implemented at a customer's facility.

Demand-side management measures: Any hardware, equipment, device, or practice that is installed or instituted resulting in increased efficiency in the utilization of energy at an energy consumer's facility, and/or shifts the timing of a customer's consumption of electricity so as to lower the overall costs to society of providing power. Demand-side management measures can include fuel-switching.

Demand-side management programs: Planned efforts, implemented by utilities or other organizations, to influence energy consumers to adopt or use one or more DSM measures.

Direct current (DC): Current which does not alternate between positive and negative polarity with respect to ground.

Discount rate: A rate at which the value of money changes over time, discount rates are applied to future costs or benefits to reflect the fact that funds received in the present are worth more than funds received some time in the future. Discount rates are used in computing present value and net present value of streams of benefits or costs.

Dispatching: The operating control of an integrated electric system to: 1) assign load to specific generating stations and other sources of supply to effect the most reliable and economical supply as the total of the significant area loads rises or falls, 2) control operations and maintenance of high-voltage lines, substations, and equipment, including the administration of safety procedures, 3) operate the interconnection, and 4) schedule energy transactions with other interconnected electric utilities.

Dispatchability: The ability of the utility to schedule and control, directly or indirectly, manually or automatically, the generating plants and DSM measures.

Dispatch Order: The order of priority in which each unit of generation capacity is selected for operation during a given time interval.

Disposal: Final placement or destruction of toxic, radioactive, or other wastes; surplus or banned pesticides or other chemicals; polluted soils; and drums containing hazardous materials from removal actions or accidental releases. Disposal may be accomplished through use of approved secure landfills, surface impoundments, land farming, deep well injection, ocean dumping, or incineration.

Distribution: The process of transferring electricity from the transmission system to final users. Electricity is distributed along local networks of overhead and/or underground power lines.

E7 Group: An association of some of the largest electric utilities in the Group of Seven (G7) industrialized nations. The E7 Group created the “E7 Network of Expertise for the Global Environment to act as a pro bono environmental, technical and industrial advisory group for electric utilities and governments in developing and Eastern European countries”.[164]

Economic dispatch: The start-up, shutdown, and allocation of load to individual generating units to effect the most economical production of electricity for customers.

Ecosystem: The interacting system of a biological community and its nonliving environmental surroundings.

Effectiveness measure: The criterion for measuring the degree to which an objective (for example, an IRP objective) has been attained.

Emission: Pollution discharged into the atmosphere from smokestacks, other vents, and surface areas of commercial or industrial facilities, from residential chimneys; and from motor vehicle, locomotive, or aircraft exhausts.

Emission factor: The relationship between the amount of pollution produced and the amount of raw material processed. For example, an emission factor for a blast furnace making iron would be the number of pounds of particulates per ton of raw material.

End-use: Useful work, such as light, heat, and cooling, which is produced by electricity or other forms of energy.

Energy, electric: As commonly used in the electric utility industry, a synonym for kilowatt-hours.

Energy, off-peak: Energy that is supplied during periods of relatively low system demands as specified by the supplier.

Energy, on-peak: Energy that is supplied during periods of relatively low system demands as specified by the supplier.

Energy efficiency measure: A technology, device, piece of equipment, behavioral change, or other action that allows an energy service to be provided using less fuel (for example, less electricity).

Energy efficiency program: A DSM program aimed at reducing overall electricity consumption (kWh). Such savings are generally achieved by substituting technically more efficient equipment to produce the same level of end-use services with less electricity. Compare with conservation; contrast with load management.

Energy services: Those services provided to society by (or partially by) the consumption of fuels. Examples of energy services include transporting a person one kilometer, boiling a liter of water for tea, or making a tonne of cement "clinker" from limestone and other ingredients. In each case, the application of different technologies and/or fuels uses different amounts of energy, but produces the same *energy service*.

Environment: The sum of all external conditions affecting the life, development, and survival of an organism.

Environmental assessment (EA): A process whose breadth, depth, and type of analysis depend on the proposed project. EA evaluates a project's potential environmental risks and impacts in its area of influence and identifies ways of improving project design and implementation by preventing, minimizing, mitigating, or compensating for adverse environmental impacts and by enhancing positive impacts.

Environmental impacts: Physical impacts on the environment (air, land and water) associated with the full fuel-cycle, that is, the development, extraction, processing, transportation, storage and combustion of fuels. If these impacts are measured relative to a specific point in the fuel-cycle, such as the point of combustion, they may be categorized as "upstream" or "downstream," that is, occurring earlier or later in the fuel cycle than the reference point.

Expansion Plan: The schedule of planned power-supply investments to produce sufficient electricity (including reserve margins) to meet forecasted future demand.

External costs and benefits (externalities): Costs or benefits from production or consumption that are not accounted for in market prices. Costs and benefits that do not have market value, and thus current or projected prices, are externalities. For example, the costs of damage to human health from certain air pollutants are negative environmental externalities.

Exposure: A potential health threat to the living organisms in the environment due to the amount of radiation or pollutant present in the environment.

Flexible AC Transmission System (FACTS): Transmission technologies based on power electronics and advanced control technologies that are used to optimize AC power flows and increase grid stability.

Fly ash: Noncombustible residual particles from the combustion process carried by flue gas.

Food chain: A sequence of organisms each of which uses the next lower member of the sequence as a food source.

Frequency: The rate at which an alternating current changes from positive to negative polarity, measured in cycles per second, or *hertz (Hz)*.

Fugitive emissions: Emissions not caught by a capture system.

Greenhouse effect: The warming of the Earth's atmosphere caused by a buildup of carbon dioxide or other trace gases; many scientists believe that this buildup allows light from the sun's rays to heat the Earth but prevents a counterbalancing loss of heat.

Groundwater: The supply of fresh water found beneath the Earth's surface (usually in aquifers), which is often used for supplying wells and springs. Because groundwater is a major source of drinking water, there is growing concern about areas where leaching agricultural or industrial pollutants or substances from leaking underground storage tanks are contaminating it.

Habitat: The place where a population (such as human, animal, plant, or microorganism) lives, and its surroundings, both living and nonliving.

Hazardous wastes: By-products of society that can pose a substantial or potential hazard to human health or the environment when improperly managed. Substances classified as hazardous wastes possess at least one of four characteristics—ignitability, corrosivity, reactivity, or toxicity—or appear on special lists.

Heat rate: Generating unit efficiency, usually expressed in BTU's (British Thermal Units), kilojoules, or kilocalories of input energy required to produce a kWh of electrical output in a given power plant.

Heavy metals: Metallic elements with atomic number greater than 20, such as mercury and lead. They can damage living things at low concentrations and tend to accumulate in the food chain.

Hertz (Hz): See Frequency.

Hydrocarbons (HC): Chemical compounds that consist entirely of carbon and hydrogen.

Impedance: The sum of resistance and reactance, measured in ohms.

Incremental cost: As used in demand-side management options review, incremental cost is the difference in cost between an alternative (typically, electric energy-saving) appliance, piece of equipment, device, or procedure (that is, a DSM measure for the provision of an energy service) and a standard appliance, piece of equipment, device, or procedure (that is, the means by which the energy service would be provided in the absence of the DSM measure). As a simple example, if a higher-than-standard efficiency refrigerator costs 1500 LE, and a standard refrigerator costs 1200 LE, then the incremental cost for a purchaser of a new refrigerator choosing the higher-than-standard efficiency unit would be 300 LE.

Independent System Operator (ISO): For example, the operator of an electricity transmission system that is governed independently from the generation organizations that feed power to the transmission system and the distribution utilities and/or other customers that take power from the transmission system.

Inductance: The property of an electric circuit that causes an electromotive force to be generated by a change in the current flowing; a physical phenomenon that can impede the flow of current.

Integrated resource planning (IRP): The process of planning for meeting all or a portion of the energy service needs of a utility's customers over the planning period (20 years). Integrated resource planning includes systematic consideration of needs (demand forecasting), electricity supply alternatives, demand-side management resources, and the environmental impacts and other "externalities" of plans that combine supply- and demand-side alternatives. Integrated resource planning selects a Preferred Plan (and, if needed, Contingency Plans) and justifies the selection of the plan with regard to planning objectives selected at the outset of the process.

Investment costs: With regard to DSM measures or supply-side infrastructure purchase, investment costs will denote the capital cost of a purchase, sometimes including costs of financing the purchase as well.

Intertie: An interconnection permitting passage of current between two or more electric utility systems.

Joule: A unit of energy in the metric (MKS) system. One joule equals one watt-second, or 1 $kg\text{-}m^2/s^2$, or $9.48x10^{-4}$ Btu, or 4.184 calories (cal).

Kyoto Protocol: At a conference held in December 1997, in Kyoto, Japan, the Parties to the United Nations Framework Convention on Climate Change agreed to a Protocol to reduce greenhouse gas emissions.

Levelized cost: The uniform annual cost that results in the same net present value over the planning horizon as the stream of actual annual average costs. An example of a levelized cost is a monthly mortgage payment. When comparing, for example, the cost of electricity production from different types of power plants, the **nominal levelized cost** is the uniform cost of electricity, in mixed current year (nominal) dollars, for which the present value of the cost of electricity produced over the life of the plant is equal to the present value of the costs of the plant, while the

real levelized cost is the uniform cost of electricity, in constant (real) dollars, for which the present value of the electricity produced equals the present value of the costs of the plant.

Life-cycle costs: The full cost of owning and operating an appliance, piece of equipment, or other energy-using device over the lifetime of the device. Life-cycle costs include the purchase, installation, operating and maintenance, energy, and sometimes externalities costs incurred over the lifetime of the device, typically discounted to calculate a net present value.

Light-water reactor (LWR): The type of nuclear power generation reactor most common in most countries.

Line losses: Kilowatt-hours and kilowatts lost in the transmission and distribution lines under specified conditions.

Load: The power drawn by an end-use device or customer connected to the power system.

Load building programs: Utility sponsored efforts designed to increase customer usage of the fuel provided by the sponsoring utility.

Load-duration curve: A graph showing a utility's hourly demand, sorted by decreasing size, and the amount of time a given level of demand is exceeded during the year.

Load factor: The ratio of average requirements to peak requirement for the same time period. Load factor may be calculated for a customer, customer class or the entire system. An "improved" load factor implies that the peak requirement is reduced while average requirement is held constant, such that there is an increase in the ratio of the average to peak requirement.

Load-following: The ability of a supply resource to respond to variations in demand.

Load forecasting: See demand forecasting.

Load management: The controlling, by rescheduling or direct curtailment, of the power demands of customers or groups of customers in order to reduce the total load that a utility must meet at times of peak demand. Load management strategies are designed to either reduce or shift demand from on-peak to off-peak, while conservation (see energy efficiency) strategies reduce net usage over larger multi-hour periods. Load management may take the form of normal or emergency procedures. Utilities often encourage load management by offering customers a choice of service options with varying price incentives (including Time-of-Use tariffs).

Load shape: The time-of-use pattern of customer demand for energy.

Load shedding: The turning off of electrical loads to limit peak electric demand.

Load shifting: Shifting load from peak to off-peak periods. Applications include use of storage water heating, storage space heating, cool storage, and customer load shifts to take advantage of time-of-use or other special rates.

Loss of load probability (LOLP): A measure of the probability that system demand will exceed available capacity during a given period.

Methane: A colorless, nonpoisonous, flammable gas created by anaerobic decomposition of organic compounds.

Modeling: An investigative technique using a mathematical or physical representation of a system or theory that accounts for all or some of its known properties. Models are often used to test the effect of changes in system components on the overall performance of the system.

Monitoring: Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements or pollutant levels in various media or in humans, animals, and other living things.

Net present value: See Present value.

Nitrogen oxides (NO_x): Products of combustion from transport and stationary sources and major contributors to acid deposition and the formation of ground-level ozone in the troposphere.

Objective: A statement of the end-result, product, or condition desired, for which a course of action is taken. In an IRP, for example, an objective is an end-result desired from the implementation of a resource plan.

Ohm(Ω): A measure of resistance.

Operating and Maintenance costs (O&M costs): Recurring costs of operating, supporting, and maintaining infrastructure or programs, including costs for labor, materials, supplies, other current expenses, and (if not accounted for separately) fuel.

Peaking Unit: A power generator used by a utility to produce extra electricity during peak load times.

Pollutant: Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the U.S. Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, and radiological integrity of water.

Power: The rate of energy flow, measured in watts (W).

Power factor: A measure of the extent to which a load is resistive; power factor is equal to the cosine of the phase difference between the current and the voltage through the load.

Present value: The current value of a cost or stream of yearly costs that have been discounted to reflect the fact that future benefits or expenditures are worth less than current benefits or expenditures. Also called Present Worth. See Discount Rate.

Program: A combination of resources and activities designed to achieve an objective or objectives.

RAINS-Asia: Regional Air Pollution INformation and Simulation-Asia, a modeling project and software tool for simulating the sources and impacts of “acid precipitation” in Asia.

Reactance: The collective term for inductance and impedance.

Reactive power: Power that is consumed by reactances, measured in volt-amperes reactive (VAR).

Real power: Power that is consumed by resistances, measured in watts (W).

Renewable resource: Any facility, technology, measure, plan or action utilizing a renewable "fuel" source such as wind, solar, biomass, geothermal, waste, or small-scale hydroelectric energy.

RERA: Southern Africa’s Regional Electricity Regulators Association.

Reserve Margin: The difference between an electric system’s maximum capacity and the expected peak demand.

Resistance: The degree to which an object resists the flow of current. Resistance, the reciprocal of conductance, is measured in ohms (Ω). The resistance of wire is a product of its resistivity (an inherent property of the material from which it is made, such as copper or aluminum, for a given temperature) and the dimensions of the wire.

Revenue requirements: The amount of revenues that a utility needs to receive in order to cover operating expenses, pay debt service, and provide a fair return to common equity investors.

Risk: Potential changes in the net present value of revenue requirements and the electric tariffs associated with a particular resource portfolio, which result when the probability distributions associated with the various planning assumptions (for example, demand forecasts, fuel prices, technology costs, or other parameters) are considered.

Runoff: That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water; it can carry pollutants from the air and land into the receiving waters.

Sediments: Soil, sand, and minerals washed from land into water, usually after rain. Sediments pile up in reservoirs, rivers, and harbors, destroying fish-nesting areas and holes of water animals and clouding the water so that needed sunlight may not reach aquatic plants. Careless farming, mining, and building activities will expose sediment materials, allowing them to be washed off the land after rainfalls.

Societal Cost: The total cost of a resource to society as a whole, including both "internal" costs (those costs already associated with a monetary value) and "external" costs, whether associated with a monetary value or not. Societal costs are evaluated independent of who in society pays the costs or receives benefits.

Solid wastes: Nonliquid, nonsoluble materials, ranging from municipal garbage to industrial wastes, that contain complex, and sometimes hazardous, substances. Solid wastes include sewage sludge, agricultural refuse, demolition wastes, and mining residues. Technically, solid wastes also refer to liquids and gases in containers.

Spinning Reserve: Electric power available from generating units connected to the system and ready to deliver power promptly.

Stakeholders: Groups and individuals who will or could be directly affected by the plans and activities related (for example) to an electricity interconnection. Examples include not only the different public companies operating in the sector, but consumers, local residents, other government agencies, environmental and other non-governmental organizations, and business groups.

Strip mining: A process that uses machines to scrape soil or rock away from mineral deposits just under the earth's surface.

Sulfur dioxide (SO_2), or Sulfur Oxides (SO_x): A heavy, pungent, colorless, gaseous air pollutant formed primarily by processes involving fossil fuel combustion (usually coal or heavy fuel oil).

Supply-side planning: Planning for the infrastructure used to supply electricity to users, which can include central, local or distributed generation capacity and related equipment such as fuel supply and emissions control devices, transmission infrastructure, and distribution infrastructure.

Supply-side resource: A resource that can provide electrical energy or capacity to a utility. Supply-side resources can include utility-owned generating facilities, and energy or capacity purchased from other utilities (such as EETC) and non-utilities.

Surface water: All water naturally open to the atmosphere (rivers, lakes, reservoirs, streams, impoundments, seas, estuaries, etc.); also refers to springs, wells, or other collectors that are directly influenced by surface water.

Tailings: Residue of raw materials or waste separated out during the processing of crops or mineral ores.

Tie Line (or Intertie): A circuit connecting two or more control areas or systems of an electric system.

Transmission: The bulk transport of electricity via high voltage lines.

Unbundling: Disaggregating electric utility service into its basic components and offering each component separately for sale with separate rates for each component. For example, generation, transmission and distribution could be unbundled and offered as discrete services.

Unserved Energy: The expected amount of energy curtailment per year due to demand exceeding available capacity. It is usually expressed in megawatt-hours (MWh).

Uprating: Increasing the rating or stated measure of generation or transfer capability.

Valley filling: The building of off-peak loads. An example of valley filling technology is thermal storage (water heating and/or space heating or cooling) that increases nighttime loads and reduces peak period loads. Valley filling may be desired in periods when the long-run incremental cost of supply is less than the average price of electricity. (Adding off-peak load under those circumstances decreases the average price.)

Volatile organic compound (VOC): Any organic compound that participates in atmospheric photochemical reactions; generally have a boiling point of less than 145° Celsius.

Volt (V): The measure of voltage.

Voltage: The difference in electric potential between two points in an electric circuit.

Water pollution: The presence in water of enough harmful or objectionable material to damage water quality.

Watershed: The land area that drains into a stream or river.

Watt (W): A unit of power equal to a Joule of energy per second.

Watt-hour: The total amount of energy used in one hour by a device that requires one watt of power for continuous operation. Electric energy is commonly sold by the kilowatt-hour (defined above).

Wetlands: An area that is regularly saturated by surface water or groundwater and is subsequently characterized by a prevalence of vegetation adapted for life in saturated soil conditions. Examples include swamps, bogs, fens, marshes, and estuaries.

Wheeling: The contracted use of electric facilities of one or more entities to transmit electricity for another entity.

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[163] The entries in this Glossary and List of Acronyms draw upon a variety of sources, and sometimes adopt text from those sources verbatim. Major sources used include the "Glossary" volume of Regional Electricity Cooperation and Integration (RECI): E7 Guidelines for the pooling of resources and the interconnection of electric power systems (Hydro-Quebec, October 2000); prepared by the E7 Network of Expertise for the Global Environment and available from http://www.e7.org; the World Bank Group, Pollution Prevention and Abatement Handbook: Glossary of Environmental Terms, available as http://lnweb18.worldbank.org/ESSD/envext.nsf/47ByDocName/WorldBankPollutionPreventionandAbatementHandbookGlossaryofEnvironmentalTerms199881KBPDF/$FILE/WorldBankPollutionPreventionandAbatementHandbookGlossaryofEnvironmentalTerms1998.pdf: Swisher, J., et al., Tools and Methods for Integrated Resource Planning, (UNEP Collaborating Centre for Energy and the Environment (Risø National Laboratory, Denmark, 1997); David F. Von Hippel, and the EEIGGR IRP Project Team, Proposed Integrated Resource Planning (IRP) Framework Document for the Restructured Electricity Industry of the Arab Republic of Egypt (2002); and from other sources.

In some cases entries in this glossary are not featured in the text of the report but are included here because they are terms that a reader is likely to find useful in studying interconnection projects.

[164] Regional Electricity Cooperation and Integration (RECI), E7 Guidelines for the pooling of resources and the interconnection of electric power systems (Hydro-Quebec, October 2000), Foreword to “Guidelines” volume; repared by the E7 Network of Expertise for the Global Environment, and available from http://www.e7.org.

ANNOTATED BIBLIOGRAPHY

The bibliography provided below includes most of the documents reviewed in preparing the report *Multi-Dimensional Issues in International Electric Power Grid Interconnections*. As such, it is intended to be a resource for users of the report, providing access to original and summary materials on the topic of grid interconnections. This bibliography is not intended, however, to be an exhaustive review of all literature on the topic. DESA makes no claim as to the accuracy of the information in the documents listed below, and the inclusion of specific documents in this listing should not be interpreted as endorsement of those documents by DESA.

1. El-Sharkawi, Emad, and Michel Lokolo. *The Potential for Regionally Integrated Energy Development in Africa: A Discussion Document*. London. .The World Energy Council. October 2003. Available as: http://www.worldenergy.org/wec-geis/publications/reports/africa/foreword/foreword.asp or http://www.worldenergy.org/wec-geis/global/downloads/africa/AfricaInt03.pdf (this is the link to the PDF version).

   KEY WORDS: Africa, Interregional Power Grid Interconnections

   - This is a detailed report on the case for developing an integrated electric grid for the continent of Africa, to be used as a tool for development and poverty alleviation in the region. It outlines the benefits and costs of such a network and has a strong section on the factors that affect cooperation and integration of the continent's energy sources. The report also gives a thorough evaluation of the current state of the energy industry and of the varying levels of regional integration in Africa. There is a detailed and informative section on the geography of energy of the continent. Though the focus of the report is specifically on the African continent, it can be used for any developing country or region of the world looking to improve the consistency and distribution of its energy sources.

2. Eynon, Robert T., Thomas J. Leckey, and Douglas R. Hale. *The Electric Transmission Network: A Multi-region Analysis*. Washington, DC. The Energy Information Agency, United States Department of Energy. 2002. Available as: http://www.eia.doe.gov/oiaf/analysispaper/transmiss.html.

   KEY WORDS: North America, Interregional Power Grid Interconnections, Competitive Electricity Markets

   - This report looks at the expected increase in inter-regional power trading, and the pressure this will put on the existing electricity networks in four regions in the Northeast of the US as competitive electricity markets become more widespread. Potential negative impacts of increased inter-regional electricity trading/sharing are among the topics highlighted.

3. *Regional Electricity Cooperation and Integration (RECI): E7 Guidelines for the pooling of resources and the interconnection of electric power systems*. Prepared by E7 Network

of Expertise for the Global Environment. Hydro-Quebec. October 2000. Available as http://www.e7.org/Pages/Pu-Papers-GuidelinesRECI.html.

KEY WORDS: Interregional Power Grid Interconnections, Sustainable Development

- This is a relatively short pamphlet (approx. 20 pages) providing an overview of the topic; it is useful for seminars and training on interconnection issues. Associated with the pamphlet is a CD ROM that includes documents that examine the issues in much more detail. The main purpose of the pamphlet and CD ROM, as described by the E7 Group, is to help develop the electricity supply industry of developing countries, and to help promote and enhance the industry's contribution to the sustainable development of those countries. The document/CD ROM examines in depth the necessary conditions for the successful implementation of integrated regional electricity networks, and outlines the political, social, economic and environmental benefits from the pooling/sharing of electricity networks and resources. This is a very well-organized and relevant source of information on grid interconnections.

4. *Technical and Economic Aspects of the Establishment of a Regional Electricity Network.* United Nations Economic and Social Commission for Western Asia. 1997.

KEY WORDS: Asia, Interregional Power Grid Interconnections, Technical, Economic, Environmental

- This report examines the technical and economic aspects of creating a regional electricity network in the ESCWA (Economic and Social Commission of Western Asia) countries of western Asia. It is broken down into 5 chapters: chapter I is an overview of the interregional electric interconnections in ESCWA with a focus on the economic, technical, and environmental benefits, as well as the power system constraints and techno-economic limitations of interconnection; chapter II is an overview of the power systems of the ESCWA members; chapter III examines the varying levels of electricity interconnections between the countries of the ESCWA region; chapter IV focuses on the prospects for establishing a regional electric grid in Western Asia; and the conclusion, chapter V, looks at the technological and economic viability of creating and maintaining interconnected electricity networks in the ESCWA region.

5. Bergman, Lars, et al. *A European Market for Electricity? Monitoring Eurpoean Deregulation 2*. London, UK. Centre for Economic Policy Research, 2 Decembe r 1999. A summary of the report, entitled "An Integrated European Market", is available as http://www.cepr.org/press/MED2.htm.

KEY WORDS: Europe, Interregional Power Grid Interconnections

- This report argues that the liberalization of electricity markets in Europe is progressing, but that "new policies and radical changes are needed if markets are to be integrated and further liberalized across Europe." For a single European market of electricity to truly function efficiently, the processes must be implemented to make cross-border electricity trade just as easy as domestic trade. To accomplish this task the report argues for the implementation of access charges. The above link is for the summary of the report, not the report in its entirety.

6. Baltic Ring Electricity Co-operation Committee (BALTREL). *Towards a Common Electricity Market in the Baltic Sea Region*. Co-Financed by the European Commission. 2002. Available as http://www.baltrel.com/Reports/Baltrel_021202.pdf.

   KEY WORDS: Europe, Interregional Power Grid Interconnections, Electricity Markets

   - This report looks at the current electricity market situation in the Baltic Sea region and evaluates the procedures necessary to move towards an integrated electricity network for the region. The paper starts with a general background and brief history on the region, then examines in more detail the market rules and infrastructure in the Baltic region, and concludes with an analysis of what needs to be done to further facilitate the move towards a common electricity market in the region and the role that BALTREL can play in that process. The main goals of the "BALTREL vision" are to: improve the infrastructure for electricity exchange and trade; create conditions for competition based on responsibility for efficiency and reliability; give equal rights to all market participants and increase the right of choice for customers to choose their energy suppliers; and to achieve environmental improvements. This report provides a case study for a transitional region in the process of integrating its electricity sector.

7. Streets, David. "Environmental Aspects of Electricity Grid Interconnection in Northeast Asia". Presented at the Workshop on Power Grid Interconnection in Northeast Asia, held in Beijing, China, 14-16 May 2001. Available as: http://www.nautilus.org/archives/energy/grid/papers/streets.pdf.

   KEY WORDS: Asia, Environmental, Hydroelectric Power

   - This document examines the environmental benefits of connecting the electric grid networks of the countries of Northeast Asia, including: Russia, Mongolia, China, Japan, the DPRK, and the Republic of Korea. The focus is on how the promotion of alternative sources of energy (namely hydro and to a lesser extent nuclear) to reduce the use of coal and the integration of the electricity networks of the different countries involved could significantly help to combat the air pollution of the region and provide more widespread and consistent electricity.

8. Turvey, Ralph. "Interconnector Economics". *Energy Policy*, 2004.

   KEY WORDS: Economic, Interregional Power Grid Interconnections

   - This paper, published recently in the *Energy Policy* journal by Elsevier press, examines why grid interconnection can at times be inefficient from an economic standpoint. Turvey explains that although there are undoubtedly benefits from interconnection, they may be difficult to quantify and may not cover the costs associated with it. The paper is pretty technical in general. It starts with a brief section on definitions and descriptions of terms in the context of the paper, and then examines the costs and benefits of international grid interconnections. The third and by far biggest section of the document, entitled 'Interconnector Utilization', constitutes the bulk of Turvey's analysis.

9. Yun,Won-Cheul. *A Strategic Approach for Electric Power Cooperation in North-East Asia*. Presented at the APEC Study Center Conference Asia Pacific Economies: Multilateral vs Bilateral Relationships, held in Hong Kong, 19-21 May 2004. Available as http://fbweb.cityu.edu.hk/hkapec/Conference/Papers/Won-Cheol.pdf.

    KEY WORDS: Asia, Interregional Power Grid Interconnections, Political

    - This study creates a scenario of grid interconnection between the Russian Far East, North Korea, and South Korea to evaluate the possibility of regional electricity cooperation in North-east Asia. Through this scenario the paper looks at the electricity market structure, the prospects for the restructuring of the electric power industries in Russia and South Korea, and the political aspects related to grid interconnection with North Korea. The paper looks at two possible options for achieving a successfully integrated grid; an inter-governmental project, and a private sector led initiative, which the author finds more feasible.

10. Karekezi, Stephen, Jennifer Wangeci, and Ezekiel Manyara, *Sustainable Energy Consumption in Africa.* African Energy Policy Research Network (AFREPREN/FWD), UN DESA Final Report. May 2004. Available as http://www.un.org/esa/sustdev/sdissues/consumption/Marrakech/EnergyConsumption.pdf.

    KEY WORDS: Africa, Sustainable Development

    - The authors examine current energy consumption in three different regions in Africa, North Africa, Sub-Saharan Africa and South Africa, and discuss the need for sustainable energy consumption initiatives. The paper focuses on three consumption sectors: household, transport and agriculture. The authors argue that, if managed correctly, these industries in African countries can jump straight to sustainable energy consumption patterns, as compared to many industrialized countries that progressed from traditional energy consumption to unsustainable consumption. Although this report does not cover electric grid interconnections, there is some useful information regarding the energy consumption patterns of the three regions and categories mentioned above.

11. *Report of the World Summit on Sustainable Development.* United Nations. Johannesburg, South Africa, 26 August – 4 September 2004. Available as http://daccessdds.un.org/doc/UNDOC/GEN/N02/636/93/PDF/N0263693.pdf?OpenElement.

    KEY WORDS: Africa, Sustainable Development

    - This report summarizes the World Summit on Sustainable Development held in Johannesburg, South Africa in 2004. It covers many different topics related to sustainable development and has some specific information pertaining to poverty alleviation through increasing the number of Africans who have access to consistent energy. Additional reports on the Summit are available at: http://www.un.org/jsummit/html/documents/summit_docs.html.

12. Madamombe, Itai. "Energy Key To Africa's Prosperity: Challenges in West Africa's Quest for Electricity" *Africa Renewal*, Vol.18, No.4, January 2005. Available as http://www.un.org/ecosocdev/geninfo/afrec/vol18no4/184electric.htm.

    KEY WORDS: Africa, Interregional Power Grid Interconnections, Environmental

    - This recently-produced article in *Africa Renewal* outlines the current energy issues in West Africa and discusses the benefits that can be obtained through grid integration in this region, and in Africa in general. Madamombe focuses on the aging electricity infrastructure as one of the major problems African countries are facing. Environmental and health issues associated with energy use are raised as well, due to the fact that a large portion of the population relies on burning traditional biomass for energy. A brief outline of current and completed grid projects is included, in addition to some of the major challenges ahead regarding electric grid interconnection.

13. Wolfe, Michael, Peter Donalek and Peter Meisen. "The Economic, Environmental and Developmental Benefits of High-Voltage Interconnections between South and North America via Central America and the Caribbean". Presented at ENERLAC 93, held in Bogota, Colombia, 15-18 June 1993.
    Accessed from the Global Energy Network Institute (GENI) website at: http://www.geni.org/globalenergy/library/technical-articles/transmission/enerlac-93/economic-environmental-and-developmental-benefits/high-voltage-interconenctions-between-south-and-north-america/central-america-caribbean.shtml.

    KEY WORDS: North America, South America, Economic/Financial, Environmental, Hydroelectric

    - As the title suggests, this report looks at the benefits of a North American/South American electric grid interconnection connected through Central America and the Caribbean. The authors examine the role renewable energy, largely from hydro dams in South America, can play in grid interconnection, and the export markets that could be created. Their focus is on the economic and environmental benefits that would be achieved in the overall context of the development of the region. The authors also look at the necessary role of the international and regional banks in financing this initiative.

14. Hale, Briony. "Africa's Grand Power Exporting Plan." *BBC*, 17 October 2002. Accessed from the Global Policy Forum website as http://www.globalpolicy.org/socecon/develop/africa/2002/1017power.htm.

    KEY WORDS: Africa, Interregional Power Grid Interconnections, Hydroelectric

- This is a short news article discussing Africa's goal of linking its electric grid with Europe and the Middle East and exporting electricity abroad. The plan is centered around the Inga rapids in Democratic Republic of Congo (DRC), which is believed to be able to supply Africa with all of its energy needs and have leftover capacity to be exported and sold overseas. In addition, the article touches very briefly on the technical and financial barriers that may be a detriment to the prospect of interconnecting Africa with Europe and the Middle East in the near future.

15. Gcabashe, Thulani. "With Power Anything is Possible". Presented at the ESKOM Business Leaders Forum, *Business in Africa Online*, 27 October 2004. Available as http://www.businessinafrica.net/eskom_leaders_forum/385701.htm.

    KEY WORDS: Africa, Interregional Power Grid Interconnections

    - Thulani Gcabashe is the chief executive of ESKOM, South Africa's power utility. In his address, given last year at the 2nd ESKOM Business Leaders Forum, Gcabashe stresses the need to significantly increase the number of people who have direct access to electricity. In order to do so, regional grids will need to be established first, which will then facilitate as easier transition to a completely integrated continent.

16. Cherian, A. *Development and Operation of Trans-border Interconnections of Electric Power Grids in Afric.* United Nations, DESA. September 2003.

    KEY WORDS: Africa, Interregional Power Grid Interconnections, Political

    - This DESA paper gives a general overview of the current status of operational and planned regional interconnections in Africa, and some of the major constraints that need to be addressed. The constraints the paper examines fall into three categories: capacity, political and policy. The paper starts with a background section on electricity in Africa, then covers the constraints on interconnection as relevant to each region covered: Central Africa, East Africa, West Africa, North Africa, and Southern Africa.

17. World Energy Council. "Regional Electricity Trading: Issues and Challenges." Presented at the Workshop on Regional Power Trade, held in Kathmandu, Nepal, 19 March 2001. Available as http://64.224.32.197/Publications/shean.pdf.

    KEY WORDS: Asia, Interregional Power Grid Interconnections

    - In this paper the South Asia Regional Initiative on Energy examines the benefits of regional electricity interconnection and trade among South Asian countries in light of the growing population and increasing demand for electricity in the region. The main benefits the paper focuses on are improved security of supply, better economic efficiency, and environmental enhancement and protection implications. The paper then addresses some of the major challenges, including: technical challenges, commercial issues, the effect of subsidies on prices, the inclusion of environmental considerations, market structure differences, governance and legal issues, financial issues, and national policy and security issues.

18. *Panel Session: Status of International Connections and Electricity Deregulation in Africa*, part of the IEEE 2004 General Meeting, held in Denver CO, 6-12 June 2004. IEEE Power Engineering Society. July 2004. Available as http://www.ewh.ieee.org/cmte/ips/2004GM/2004GM_Africa.pdf.

    KEY WORDS: Africa, Interregional Power Grid Interconnections, Economic, Hydroelectric

    - This document is a very informative collection of essays written on various subjects related to regional electricity interconnections and electricity deregulation in Africa. In total there are 11 reports, most of which function as case studies representing a specific topic related to the issues outlined previously. For example, the reports cover such topics as the economic impact of interconnections for the Southern African Power Pool, and the potential positives and negatives resulting from large hydro projects through an evaluation of the 3 Gorges Dam in China. The first section of the report also provides detailed biographical information on each of the authors of the reports in the document, who presented the reports at the panel session in Colorado in 2004.

19. "Powering Africa's Development: an Interview with Thulani Gcabashe". *Global Energy Report: The Future of African Energy*. London, UK. First Magazine and World Energy Council. 2003. Available as http://www.worldenergy.org/wec-geis/global/downloads/first/africa/gcabashe.pdf.

    KEY WORDS: Africa, Interregional Power Grid Interconnections

    - This interview with the Chairman of ESKOM, Thulani Gcabashe, is directed towards his company's directives and future plans of growth and expansion in Africa, and his thoughts on the energy situation in Africa more generally. The interview also looks at ESKOM's role in regional initiatives, such as the New Partnership for Africa's Development (NEPAD), the SAPP, and the Union of Producers, Conveyers and Distributors of Electrical Energy in Africa (UPDEA), in which ESKOM is integrally involved. Gcabashe also discusses the importance of developing an integrated, continent wide electric grid as a method for poverty alleviation.

20. Vladislav Vucetic. *South Asian Regional Energy Trade: Opportunities and Challenges*. The World Bank. October 2004. Available as http://siteresources.worldbank.org/INTSOUTHASIA/Resources/Energy_a.pdf.

    KEY WORDS: Asia, Interregional Power Grid Interconnections

    - This paper gives a general overview of the current energy situation in South Asia, including installed capacity and production information for Bangladesh, Bhutan, Nepal, Pakistan, Afghanistan, Iran, India, and Sri Lanka. The paper also includes a brief section on interregional trade in comparison to the levels of trade in other regions of the world. A rationale for interregional energy trade in South Asia is given, including the benefits, costs, and obstacles.

21. Enrique Crousillat, "Developing International Power Markets in East Asia", *Public Policy Journal*. Note No. 143. May 1998. Available as http://rru.worldbank.org/Documents/PublicPolicyJournal/143crous.pdf.

    KEY WORDS: Asia, Interregional Power Grid Interconnections

    - This "note", as it is referred to by the author, describes the different market development options for regional power trade in East Asia, examines the reforms of the power industry, looks at the benefits from and obstacles to regional electricity trade, and gives a brief overview of the efforts and current infrastructure regarding power trade in the greater Mekong region. This area includes Cambodia, Laos, Vietnam, the Yunnan Province of southern China, Myanmar, and Thailand.

22. *Theun-Hinboun Hydropower - Project Profile*. Asian Development Bank. Initial profile dated November 1998. Available as http://www.adb.org/Projects/TheunHinboun/.

    KEY WORDS: Asia, Hydroelectric

    - "The main objective of the Project is to support economic growth through the enhancement of foreign exchange earnings by the export of electric power to Thailand. The Project represented a new policy direction in the power subsector, which has been initiated through discussions with the Bank. It is the first time that the Government of Lao PDR formed a joint venture (JV) with the private sector for financing, construction and operation of a power plant."

23. Wayne White. *Theun-Hinboun: an assessment of early project performance*. Probe International. 1 March 2001. Available as http://www.probeinternational.org/pi/documents/mekong/TheunHinboun2.html#Introduction.

    KEY WORDS: Asia, Hydroelectric

    - This paper is an evaluation by an independent observer of the Theun-Hinboun Hydropower project between Lao PDR and Thailand. The purpose of the report is to assess the performance of the project during the first two years of its operation, based on the power generated and revenue history. Based on the company's initial findings, they report that from the perspective of the Lao Government, who borrowed money from ADB to finance the project, the project is currently performing well and will continue to do so for the duration of its lifetime (25 years).

24. *Trading Away the Future: the Mekong Power Grid*. Berkeley CA. International Rivers Network. June 2003. Available as http://www.irn.org/programs/mekong/030620.powergrid-bp.pdf.

    KEY WORDS: Asia, Hydroelectric

- In this International Rivers Network (IRN) briefing paper, the threats of the ADB-supported regional power grid in the Mekong River region, which would encourage dam construction throughout mainland Southeast Asia, are outlined and criticized.

25. Kalitsi, E.A.K. *Problems and Prospects for Hydropower Development in Africa*. Presented at the Workshop for African Energy Experts on Operationalizing the NEPAD Energy Initiative, June 2003. Available as http://www.un.org/esa/sustdev/sdissues/energy/op/nepadkalitsi.pdf.

    KEY WORDS: Africa, Hydroelectric

    - This paper outlines the prospects and problems of hydro power development in Africa and focuses on recommending concrete proposals to help facilitate the development of this sector of Africa's energy infrastructure. These policy proposals and strategies fall under the auspices of the New Partnership for African Development (NEPAD) initiative. The various sections of the paper outline Africa's power sector, the current hydro initiatives underway in Africa, the benefits and environmental and social costs associated with hydro power, funding issues, and an action plan for the development of hydro power in Africa.

26. Matinga, Margaret. "Pooling African Power: Challenges and Issues in a Reforming and Integrating Southern African Power Sector." Presented at the Workshop on Monitoring Regional Integration in Southern Africa, held in Windhoek, Namibia, 12-13 June 2004. Available as http://www.nepru.org.na/Regional%20Intergration/Power%20sector%20integration.pdf.

    KEY WORDS: Africa, Interregional Power Grid Interconnections

    - This document provides an overview of the Southern African Power Pool (SAPP), the various initiatives the Pool is undertaking and the issues it is facing. The author discusses the benefits of SAPP, including: economic efficiency, supply diversity and reliability, and the environmental benefits associated with pooling and distributing southern Africa's power sources. Also included in the paper is an overview of the various regulatory organizations involved in the SAPP and a section examining the challenges facing this power pool.

27. F.T. Sparrow and William Masters, *Modeling Electricity Trade in Southern Africa,* project proposal for funding under the USAID co-operative agreement on Equity and Growth through Economic Research/Trade Regimes and Growth (EAGER/TRADE). Purdue University. June 1997. Available as http://engineering.purdue.edu/IE/Research/PEMRG/PPDG/SAPP/1998proposal.pdf.

    KEY WORDS: Africa, Interregional Power Grid Interconnections, Technical

    - The authors of this report provide an overview of the SAPP and examine the objectives and plan of research conducted by Purdue University and planners at the Southern African Development Community (SADC) in 1997. It also outlines a long-term study proposed by these same groups to examine capacity expanding initiatives by modeling capital investments for new regional power links and cooperative construction of new power generators.

28. O'Leary, Donal, Jean-Pierre Charpentier, and Diane Minogue. "Promoting Regional Power Trade – The Southern African Power Pool." *Public Policy Journal.* Note No. 145. June 1998. Available as http://rru.worldbank.org/PublicPolicyJournal/145olear.pdf.

KEY WORDS: Africa, Interregional Power Grid Interconnections

- This article gives a brief overview of the Southern African Power Pool (SAPP), reviews the circumstances that have paved the way for the successful development of SAPP, and outlines the challenges that (at the time the article was written) lay ahead.

29. Mkhwanazi, Xolani. "Power Sector Development in Africa". *Presented at the Workshop for African Energy Experts on Operationalizing the* NEPAD Energy Initiative, held in Dakar, Senegal, 2-4 June 2003. Available as http://www.un.org/esa/sustdev/sdissues/energy/op/nepadmkhwanazi.pdf.

KEY WORDS: Africa, Power Sector Overview, Technical

- This paper was designed to provide background materials on the power sector in Africa and to promote discussion of related topics for a workshop of African energy experts in Senegal in 2003. Its primary objectives were to outline the status of the energy sector in Africa and to discuss some of the current problems it is facing, including the technical and non-technical barriers to electricity trade; to promote the need for regional and sub-regional initiatives for power sector development; and to propose strategies and policies to address infrastructural issues, and more broadly, policies promoting the further development of the power sector.

30. McCully, Patrick. "Tropical Hydropower is a Significant Source of Greenhouse Gas Emissions: A response to the International Hydropower Association". Presented at the 10th Session of the International Conference of the Parties to the United Nations Convention on Climate Change (COP10), held in Buenos Aires, Argentina, 13 December 2004. International Rivers Network. December 2004. Available as http://www.irn.org/basics/conferences/cop10/pdf/TropicalHydro.12.08.04.pdf.

KEY WORDS: Hydroelectric, Environmental

- This paper is a response to information provided by the International Hydropower Association regarding the emissions of greenhouse gases from hydro facilities. It examines the effects that large reservoirs have in terms of methane gas emissions, and also sites and critiques several reports written on greenhouse gas emissions of hydropower plants.

31. McCully, Patrick, and Susanne Wong. "Powering a Sustainable Future: The Role of Large Hydropower in Sustainable Development". Presented at the UN Symposium on Hydropower and Sustainable Development, held in Beijing, China, 27-29 October 2004. International Rivers Network. Available as http://www.irn.org/basics/conferences/beijinghydro/pdf/irnbei.pdf.

    KEY WORDS: Hydroelectric, Environmental, Economic, Social

    - The focus of this paper is on the role of large hydropower facilities in sustainable development. It looks at the social, environmental, and economic impacts that result from the limitations of large hydro plants and provides recommendations for environmentally friendly, cost-efficient, and socially equitable development for projects of this nature.

32. Bocking, Stephen. "Environmental, Social and Economic Impacts of Dams: Environmental Impacts." *Dams and Development*. International Development Studies Network. 16 October 1998. Available as http://www.idsnet.org/Resources/Dams/Development/impact-enviro.html.

    KEY WORDS: Hydroelectric, Environmental

    - This report looks at the major environmental impacts of dams, which it organizes into two categories. The first category is the impacts that arise from the existence of a dam and reservoir, such as loss of habitat, increased erosion, changes in downstream water quality, and reduction of biodiversity. The second category is the issues that arise due to the pattern of dam operation, such as changes to downstream hydrology, morphology and water quality, and also reduction in habitat diversity.

33. Pearce, Fred. "Water-Reservoirs and Greenhouse Emissions". *The Independent*. London, UK.13 October 2000. Available as http://www.rivernet.org/general/dams/greenhouse.htm.

    KEY WORDS: Hydroelectric, Environmental

    - This article examines the environmental impacts of reservoir dams, with a specific focus on greenhouse gas emissions and the resulting effect on global warming. It argues that hydroelectric power, once touted as a "green" energy source, produces significant quantities of carbon dioxide and methane, making many of the large reservoir dams as pollution-causing as a typical fossil-fuel burning plant.

34. *Environmental Impacts of Electric Transmission Lines.* PSC Overview Series. Public Service Commission of Wisconsin. 1998. Available as http://psc.wi.gov/consumerinfo/brochures/electric/60/ob.pdf.

    KEY WORDS: Environmental, Social

    - The Public Service Commission of Wisconsin provides background information on the environmental and social impacts of the construction of electricity transmission lines. The piece was designed to assist landowners, local officials, and other citizens who might be affected by the construction of such a line, and more generally to serve as a guide in helping to develop Wisconsin's long-term energy plans.

35. Alami, Randa. *Financial Aspects of Arab Power Development.* Oxford Institute for Energy Studies. January 2005. Available as http://www.oxfordenergy.org/pdfs/F9.pdf.

KEY WORDS: Middle East, Economic/Financial

- This report looks at the financial aspects of the development of the electricity sector in the Middle East. The author examines the role of public and private partnerships and the strong regional cooperation occurring in the region today in regards to the financing of power sector projects. The report begins with an overview of the current trends for financing in this industry in the developing world, then more specifically the rest of the piece focuses on developments in the Arab world.

36. New Partnership for Africa's Development text, from a conference held in Abuja, Nigeria in October, 2001. Available as http://www.uneca.org/eca_resources/Conference_Reports_and_Other_Documents/nepad/NEPAD.htm.

KEY WORDS: Africa, Sustainable Development

- The New Partnership for Africa's Development is a pledge made by Africa's leaders to eradicate poverty while simultaneously pursuing a path of sustainable development and growth. This is a general initiative that covers many different topics and issues related to poverty reduction and development, including specific information on energy and development. Some of the major objectives outlined in the report related to energy initiatives are the following: to provide clean and affordable energy to 35 per cent of the African population within 20 years; to improve the reliability and lower the cost of energy supply; and to facilitate cross-border energy flows by integrating transmission grids and pipelines.

37. US Nuclear Regulatory Commission. *Generic Environmental Impact Statement for License Renewal of Nuclear Plants*, Chapter 4. NRC Report # NUREG-1437, Vol. 1. 1996. Available as http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1437/v1/.

KEY WORDS: Nuclear, Environmental

- The purpose of this report is to assess the potential environmental impacts associated with license renewals of nuclear power plants or with the continued operation of nuclear plants for another 20 years. In addition, the report serves to provide the technical basis for amending the Nuclear Regulatory Commission's (NRC's) regulations regarding the renewal of these operating licenses.

38. Grunbaum, R., J. Charpentier, and R. Sharma. *Improving the efficiency and quality of AC transmission systems*, Joint World Bank-ABB Paper. 2000. Available as http://www.worldbank.org/html/fpd/em/transmission/efficiency_abb.pdf.

KEY WORDS: Power Sector Overview, Interregional Power Grid Interconnections

- This report looks at the opportunities and challenges presented by the fast-changing electricity supply industry, which largely stem from the significant increase in inter-utility power sharing, deregulation of the electricity market, and the political, economic and environmental aspects of building new transmission lines. The paper addresses other solutions, known as "Flexible AC Transmission Systems (FACTS)", for overcoming capacity and quality limitations as opposed to following the more traditional path of building new lines.

39. Bickel, John. "Grid Stability and Safety Issues Associated with Nuclear Power Plants". Presented at the Workshop on Grid Interconnections in Northeast Asia, held in Beijing, China, 14-16 May 2001. Available as http://nautilus.org/archives/energy/grid/papers/Bickel.pdf.

KEY WORDS: Asia Nuclear, Technical

- This paper provides a brief summary of the technical issues associated with using nuclear power generation on existing grid networks, and how there are unique requirements and standards that these grids must meet in order to safely be able to accommodate nuclear power facilities. More specifically, the paper looks at how design standards and safety regulations relate to grid reliability and nuclear safety.

40. Hughes, Thomas P. *Networks of Power: Electrification in Western Society*, 1880-1930, Baltimore, MD. Johns Hopkins University Press. 1983.

KEY WORDS: North America, Power Sector Overview, Europe, Technical,

- Thomas Hughes, a professor at the University of Pennsylvania, looks at the history of electrification of the Western world in his "Networks of Power." Hughes thoroughly examines the development of electric supply systems and outlines in detail the technology of these various systems.

41. Rincliffe, R.G. "Planning and Operation of a Large Power Pool". *IEEE Spectrum.* January 1967, pp.91-96. Available as http://blackout.gmu.edu/archive/pdf/planning_ops.pdf.

KEY WORDS: North America, Power Sector Overview, Benefits of Interregional Power Grid Interconnections

- Rincliffe looks at the history of the development of power pools in the United States, primarily focusing on the Pennsylvania-New Jersey-Maryland pool which can be dated back to 1927. The main focus of the article is tracing the evolution of interconnections into full-fledged power pools, and the benefits these pools provide.

42. Meslier, F. “Historical Background and Lessons for the Future”. *The Evolution of Electric Power Transmission Under Deregulation: Selected Readings*. J. Casazza and G. Loehr, eds. Piscataway, NJ. IEEE. 2000.

    KEY WORDS: North America, Power Sector Overview

    - Meslier’s article is part of a collection of articles on power transmission systems. The areas covered in the book as a whole include: an overview of deregulation issues; transmission system planning and design; transmission system operation; transmission transfer capacity; and restructuring, reliability and transmission.

43. Blackburn, J. *Protective Relaying: Principles and Applications*, 2nd ed. New York. Marcel Dekker. 1998.

    KEY WORDS: Power Sector Overview

    - Blackburn outlines the basic theories and applications regarding relays used in protecting electric power systems. This is the second edition of a widely-used resource, providing information on topics such as: large and small, industrial and commercial power systems; power generator protection; power system grounding; and the performance of power systems during abnormal conditions.

44. Koshcheev, L. A. “Basic Principles of Interstate Electrical Power Links Organization in North-East Asia”. Presented at the Workshop on Power Grid Interconnections in Northeast Asia, held in Beijing, China, 14-16 May 2001. Available as http://nautilus.org/archives/energy/grid/papers/koshcheev.PDF.

    KEY WORDS: Asia, Technical, Economic

    - This article looks at the technical and economic reasons for the creation of interconnected electrical ties in North-East Asia. It stresses that due to peculiarities in these ties, preference should be given to HVDC transmission systems. The paper also analyses data collected in preliminary investigations of selected interstate electrical ties in North-East Asia in 2000.

45. Overbye, Thomas. *Power System Simulation: Understanding Small- and Large-System Operations*. IEEE Power Engineering Society Techtorial. 2004. Available as http://www.ieee.org/organizations/pes/public/2004/jan/pestechtorial.html.

    KEY WORDS: Technical, Power Sector Overview

    - This simulation provides an overview of small and large-scale electric systems operations. It is part of the series, “Power System Basics for Business Professionals”, which is geared towards educating professionals in the electricity industry who have not had technical training related to power systems. This simulation builds on the foundation provided by the “Electricity Basics” portion of the course.

46. Lerner, Eric. “What’s Wrong with the Electric Grid?” The Industrial Physicist, Vol. 9, No. 5, October/November 2003, pp.8-13.

    Key Words: North America, Technical, Economic, Power Sector Overview

    - Lerner looks at the physical components of electric grids, and the economic rules that govern them, to examine the reasons why power transmissions systems fail. Lerner looks at the case of the blackout in the Northeast United States of 2003. It is his premise that to avoid such blackouts in the future, the US system must either transform to accommodate the new economic rules governing power systems, or create new rules to match the physical structure of power grids.

47. Glover, J. Duncan, and Mulukutlas Sarma. *Power System Analysis and Design*, 3rd edition. Thomson. December 2001.

    Key Words: Technical, Power Sector Overview

    - This textbook is designed to provide a general overview of the basic concepts of power systems and the tools and skills needed to apply these concepts. Basic theories and modeling techniques are presented, giving the reader a foundation which can be easily extended towards understanding some of the new and more complex issues facing the industry today. Several updated case studies are incorporated in the text book.

48. Stevenson, W. *Elements of Power System Analysis*, 4th Edition. New York, NY. McGraw-Hill Series in Electrical Engineering. 1982.

    Key Words: Technical, Power Sector Overview

    - This textbook, used often in university-level electrical engineering classes, provides an in-depth examination of the electrical theory behind generation, transmission, system protection, and power flow and system stability analysis.

49. Fitzgerald, A.E., Charles Kingsley, and Stephen D. Umans, *Electric Machinery,* 6th Edition. New York, NY. McGraw-Hill. 2003.

    Key Words: Technical, Power Sector Overview

    - This textbook introduces the basic rules of magnetic circuits, magnetic materials, transformers, and electromechanical energy conversion, then describes the operating principles of specific machines types: rotating, synchronous, induction, DC, variable-reluctance, single phase, and two-phase. (Review taken from *Book News, Inc., Portland, OR.)*

50. Ewald, Earl, and D. W. Angland, “Regional Integration of Electric Power Systems”. *IEEE Spectrum*, April 1964, pp. 96-101. Available as http://blackout.gmu.edu/archive/pdf/regional_intg.pdf.

KEY WORDS: Economic, Interregional Power Grid Interconnections

- This excerpt examines the economic concepts related to the planning of large-scale power systems, and looks at a few specific regional integration plans developed for the western United States. The authors also look at how the development of EHV and supersized generators has made a power pool consisting of 10 states and 22 utilities economically feasible.

51. Happ, H. "Power Pools and Superpools: A Description of the Methods for the Second-to-Second Control of Generation in Large Power Systems." IEEE Spectrum, March 1973, pp.54-61. Available as: http://blackout.gmu.edu/archive/pdf/power_pools.pdf.

KEY WORDS: Technical, Regional Power Pools

- This reports looks at how generation is controlled in large power pools. It starts with a review of the development of power sharing and pools, their benefits, and the key components necessary for them to function efficiently. The report then presents three different methods for controlling the generation of pools and superpools, addressing the positives and negatives of each.

52. Hicks, K. "Disaster Control Coordination for Large Interconnected Systems". *IEEE Spectrum*, November 1967, pp.52-55. Available as http://blackout.gmu.edu/archive/pdf/disaster_control.pdf.

KEY WORDS: Technical, Interregional Power Grid Interconnections

- Hicks looks at the new approaches to confronting interconnection problems and the coordination of disaster control efforts that evolved in the 1960's to combat the possibility of widespread power failures in the United States. In this article, Hicks also provides methods for load shedding, spinning-reserve rules, and area separation.

53. North American Electric Reliability Council (NERC). *Transmission Transfer Capability: A Reference Document for Calculating and Reporting the Electric Power Transfer Capability of Interconnected Systems*. May 1995. Available as ftp://ftp.nerc.com/pub/sys/all_updl/docs/pubs/TransmissionTransferCapability_May1995.pdf.

KEY WORDS: North America, Technical, Interregional Power Grid Interconnections

- This report looks at the capability of transmission transfers from the standpoint of a transfer system's physical limitations and core characteristics. Various definitions, concepts, technical issues, and simulations used to calculate and report transmission transfer capability are also presented to provide background information related to transfer capability.

54. Verneyre, Francois. "European Challenges, Overcoming Challenges". Presented at the KEEI & IEA Joint Conference on Northeast Asia Energy Security and Regional

Cooperation, held in Seoul, South Korea, 16-17 March 2004. Available as http://www.keei.re.kr/web_keei/en_news.nsf/0/4dfb5e1e76aa3c1349256e4800150eab/$FILE/Francois%20Verneyre.pdf.

KEY WORDS: Europe, Asia, Technical, Interregional Power Grid Interconnections

- This presentation looks at the various components, issues and challenges of the European electricity industry, and what East Asia can learn from it. The major issues to be examined include: fragmented markets, blackouts and their causes, and price spikes. The challenges looked at include: the security of supply and the realization of IEM (Internal Electricity Market), and associated challenges such regional integration and creating a balanced energy mix.

55. Biewald, Bruce, et al, *Societal Benefits of Energy Efficiency in New England*. Tellus Institute, 8 November 1995. Available as http://www.cs.ntu.edu.au/homepages/jmitroy/sid101/npfdsm.html.

KEY WORDS: North America, Social, Environmental

- This report examines the social benefits of Demand Side Management (DSM) relating to electric power generation in New England. It specifically focuses on the health, environment and public amenities resulting from the reduced demand of power generation that DSM can provide.

56. Joskow, Paul, and Edward Kahn. *A Quantitative Analysis of Pricing Behavior In California's Wholesale Electricity Market During Summer 2000: The Final Word*. Cambridge-MIT Institute, University of Cambridge. February 2002. Available as http://stoft.com/metaPage/lib/Joskow-KahnE-2002-CA-Mrkt-Pwr-Final.pdf.

KEY WORDS: North America, Economic

- The purpose of this report is to examine the price surge of electricity in California during the summer of 2000, and to provide an explanation for why this extreme price increase occurred. It begins by looking at normal changes to supply and demand in the market to determine how much of the price increase occurred naturally. The second section of the paper looks at how much of an effect the trading of NO_x permits had on the price of electricity, while the final section of the report looks at whether or not the gap between the benchmark of competitive prices and the actual prices fits with the available data on supplier behavior.

57. *Electric Power System Interconnection Agreement between CLECO Power LLC and the Southwestern Power Company*, Rate Schedule FERC No. 17, section 5.15. 28 November 2001. Available as http://www.cleco.com/uploads/RS17.pdf.

KEY WORDS: North America, Legal

- This document is a typical example of a power purchase agreement (PPA) between two companies in the United States and is therefore a good legal reference for what information is generally covered in a PPA.

58. Kay, Robert. "Impact of the Financial Crisis on the Energy Sector: a Developer's Perspective". Presented at Energy Week 1999: The Global Shakeout. The World Bank. 1999. Available as http://iris37.worldbank.org/domdoc/PRD/other/PRDDCONTAINER.nsf/ALL+Documents/85256D2400766CC7852570060052D26D/$File/kay_pres.pdf.

KEY WORDS: Asia, Economic

- This papers looks at the impact the Asian financial crisis had on the financing of new power projects in Southeast Asia, and on the role of private sector producers in energy projects more generally. It specifically examines the experience of GMS Power Public Company Ltd. in regards to a project it completed after the crisis began.

59. Neuhoff, Karsten. "Economic Considerations for International Electricity Interconnections in North-East Asia." Presented at the Workshop on Power Grid Interconnection in Northeast Asia, held in Beijing, China, 14-16 May 2001. Available as http://www.nautilus.org/archives/energy/grid/papers/neuhoff.pdf.

KEY WORDS: Asia, Economic, Interregional Power Grid Interconnections

- Neuhoff looks at the economic aspects of grid interconnection between Russia, DPRK, and the Republic of Korea in relation to the experiences of other countries. His focus is strictly on the economic benefits to be obtained, and the paper stresses that political aspects of interconnection are intentionally left out of the analysis. The first section of the paper analyses the economic benefits, while the second examines how the benefits would be attributed to the various parties involved. Neuhoff also looks at the financing options for interconnection, and stresses that public/private partnerships, public ownership or ownership by the national transmission grids are preferable.

60. The UN Global Compact. United Nations. Available as http://www.unglobalcompact.org.

KEY WORDS: Economic, Interregional Power Grid Interconnections

- This website includes a number of references, case studies and tools in areas relevant to assessing the social benefits and costs of business ventures (such as interconnections and other large energy ventures) and their impacts on sustainable development. Issues such as transparency and multi-stakeholder processes are covered in documents (including the Banfield, et al. document referenced below) available on the UN Global Compact site.

61. Vucetic, Vladislav. “World Bank’s South Asia Energy Program.” Presented at the SARI/Energy Semi Annual Meeting, held in New Delhi, India, 12-13 October 2004. Available as http://sari-energy.org/PPTdisplay.asp/presentationID=PPT103OCT04.

    KEY WORDS: Asia, Power Sector Overview

    - This PowerPoint presentation looks at the energy environment of South Asia and outlines some of the major issues and challenges facing the region today. It briefly outlines the installed power generation capacity of each country and discusses the rising demand for energy in the region as a whole. The presentation examines in detail seven countries, including: Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka.

62. Banfield, Jessica , Adam Barbolet, Rachel Goldwyn, and Nick Killick. *Conflict-Sensitive Business Practice: Guidance for Extractive Industries*. London, UK. International Alert. March, 2005. Available as http://www.international-alert.org/pdf/pubbus/conflict_sensitive_business_practice_all.pdf.

    KEY WORDS: Environment, Sustainable Development

    - This report examines the role that businesses in extractive industries (such as oil, gas and mining projects) can have in developing countries, and how these businesses, if inadequately prepared to operate in a potentially unstable environment or managed improperly, can often times be a catalyst for conflict within a region. The report provides information on understanding conflict risk and how, in the sphere of corporate social responsibility, businesses can be better prepared to work in societies at risk of conflict.

63. Von Hippel, D. F. and J. H. Williams. “Environmental Issues for Regional Power Systems in Northeast Asia”. Presented at the Third Workshop on Power Grid Interconnections in Northeast Asia, held inVladivostok, Russian Federation, 30 September – 3 October 2003. Available as: http://nautilus.org/archives/energy/grid/2003Workshop/Env_Issues_DVH_JW_final_pdf.PDF

    KEY WORDS: Environment, Interregional Power Grid Interconnections

    - This report looks at the positive and negative environmental impacts of power grid interconnections in Northeast Asia. The main areas of focus of the report include air pollution, water pollution, solid and hazardous waste, land use, biodiversity and wildlife, and human health. The final sections of the paper evaluate the institutional issues related to the environmental impact of power grid interconnections.

64. Vallée, A., and G. Jean Doucet, “Environmental Implications or International Connections: The New Arena”, *IEEE Power Engineering Review*, August 1998, and presented at the panel session on International High-Voltage Grids and Environmental Implications at the 1998 IEEE Power Engineering Society Winter Meeting, held in Tampa FL. Available as http://www.geni.org/energy/library/technical_articles/transmission/IntlGridandEnvironment.html.

KEY WORDS: Asia, Africa, Europe, North America, Environment, Interregional Power Grid Interconnections

- This report looks at the environmental impacts resulting from interregional power grid interconnections, focusing on case studies from North Africa, East Asia, Europe and North America, and at quality of life and renewable energy opportunities with long distance transmission. It is segmented into seven different sections covering these topics respectively.

65. Kang, Jungmin. “Environmental Impacts and Benefits of Regional Power Grid Interconnections for the Republic of Korea: Potential Impacts on Nuclear Power Generation and Nuclear Waste Production.” Presented at the Third Workshop on Grid Interconnections in Northeast Asia, held in Vladivostock, Russian Federation, 30 September – 3 October 2003. Available as http://www.nautilus.org/archives/energy/grid/2003Workshop/Jungmin_KANG_final.pdf.

KEY WORDS: Asia, Environment, Interregional Power Grid Interconnections

- This report examines the environmental impacts and benefits of interregional power grid interconnections, with a focus on nuclear power generation in the Republic of Korea. More specifically it looks at the economic and environmental benefits that Korea could obtain by importing power from Russia, thereby reducing the waste generated during nuclear power production.

66. World Bank, *Environmental Assessment Source Book*. Washington, D.C., USA. World Bank. 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.

KEY WORDS: Environment, Sustainable Development

- This source book, published by the World Bank, is intended to assist all those working on issues of environmental assessment (EA). It follows the main premise that sustainable development is achieved when negative environmental externalities are identified and targeted at the earliest possible stage of the planning and development of a project. It also serves to provide specific information for EA professionals, the World Bank, and governments borrowing from the Bank regarding environmental assessment.

67. The United States Environmental Protection Agency, *AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources*, often referred to simply as "AP-42". Available in multiple sections and volumes 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 no long maintained; however, the most recent version is available as http://www.epa.gov/otaq/ap42.htm.

    KEY WORDS: Environment

    AP-42 and the CHIEF website offer a comprehensive set of source documents and databases for emission factors for all sorts of air pollutant-producing processes.

68. Intergovernmental Panel on Climate Change, *IPCC Guidelines for National Greenhouse Gas Inventories*. Revised 1996 versions of the three-volume *Guidelines* documents are available as http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

    KEY WORDS: Environment

    - These international guidelines provide 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. .

69. Charles Concordia. "Electric power systems: past, present, and future", *IEEE Power Engineering Review*, Feb. 1999, pp. 7-8. Abstract available from http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?isnumber=16028&arnumber=743416&count=4&index=0, full text available online by subscription. Abstract from article as quoted from this source above is as follows:

    - "The author mostly discusses the future of electric power systems, mentioning the past primarily to point out mistakes and so, hopefully, to avoid repeating them. The author discusses frequency and voltage control, complexity of systems, energy sources, and structure of the electric utility industry."

70. Casazza, John. "Blackouts: Is the Risk Increasing?" *Electrical World*, Vol. 212, No.4. April 1998, pp. 62-64.

71. Edris, A. "FACTS Technology Development: An Update," *IEEE Power Engineering Review*, March 2000, pp. 4-9. Abstract available from http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?isnumber=17866&arnumber=825623&count=8&index=0; full text available online by subscription. Abstract from article as quoted from this source above is as follows:

    - "This overview of the FACTS program sponsored by EPRI identifies the significant challenges and the adopted technology-based solutions that have been developed. FACTS technology has been successfully demonstrated and continues to be implemented at transmission locations in the United States. A STATCOM, UPFC, and convertible static compensator are discussed. The installed FACTS controllers have provided new possibilities and unprecedented flexibility aiming at maximizing the utilization of transmission assets efficiently and reliably. As the development and implementation of FACTS controllers evolve, there will be a need for an overall controller "hierarchical" logic to optimize transmission system operations."

72. Stahlkopf, Karl, and Philip Sharp. "Reliability in Power Delivery: Where Technology and Politics Meet." *Public Utilities Fortnightly*, Vol. 136, No.2, 15 January 1998, pp.30-33. Available by subscription from http://www.pur.com/puftocs/jan1598.cfm.

73. Reason, John. "Special Report: Transmission Structures," *Electrical World,* Vol. 206, No. 3, March 1992, pp. 31-49.