INTERNATIONAL ENERGY AGENCY

IMPLEMENTING AGREEMENT FOR
HYDROPOWER TECHNOLOGIES
AND PROGRAMMES

ANNEX III

HYDROPOWER AND THE ENVIRONMENT:

PRESENT CONTEXT AND GUIDELINES FOR FUTURE ACTION

Subtask 5
Report

VOLUME II:
Main Report

May 2000

TECHNICAL REPORTS IN THIS SERIES

Hydropower Upgrading Task Force (Annex 1)
Guidelines on Methodology for Hydroelectric Turbine Upgrading by Runner Replacement – 1998 (available to non-participants at a cost of U.S. $1,000 per copy)

Guidelines on Methodology for the Upgrading of Hydroelectric Generators – to be completed in May 2000

Guidelines on Methodology for the Upgrading of Hydropower Control Systems – to be completed in 2000

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Brochure
A brochure is available for the general public. Entitled "Hydropower – a Key to Prosperity in the Growing World", it can be found on the Internet (www.usbr.gov/power/data/data.htm) or be obtained from the Secretary. (address on the inside back cover)

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We wish to thank the Annex III team for the constant support, drafting and on-going review of this Subtask report: Shuichi Aki, Svein Båtvik, Magnus Brandel, David Corregidor, Rune Flatby, Geir Hermansen, Sverre Husebye, Raimo Kaikkonen, Joseph Milewski, Hannu Puranen, Cristina Rivero, Björn Svensson, Jens Petter Taasen, Serge Trussart, Kiyoaki Uchikawa.

To our reviewers and colleagues, and those who spent long hours collaborating on sections of the report: Camille Bélanger, Gilles Bérubé, Louis Chamard, Yves Comtois, Dominique Egré, Luc Gagnon, Louis Gilbert, Frans Koch, Danielle Messier, Engelbert Oud, Martin Pérusse, Vincent Roquet, Louise Roy, Karin Seelos, Pierre Sénécal, Tor Ziegler.

To the Executive Committee for their guidance and comments,

To Jocelyne Baril for her patient editing,

To all those who took time to comment, review, edit and generally improve the contents of this report.

Montréal, 1 April 2000

Jean-Étienne Klimpt, Canadian Representative, Annex III Subtask 5 Leader

Annex III

I wish to thank the Annex III team, their companies and experts for the support and constructive and professional participation during all these 5 years. The Expert Meetings and Workshops have been characterized by an open, friendly and informal atmosphere, which have ensured common understanding with regard to professional content and the decisions made. During the 11 meetings the work has progressed steadily, with no steps back caused by misunderstandings or unclear decisions. Special thanks go to the National Representatives, Subtask Leaders and the Annex III Secretary for their enthusiasm, co-operation and achievement. On behalf of all the participants in our meetings and workshops, I would like to express our appreciation to the companies which were our hosts: Vattenfall, ENEL, UNESA, CRIEPI, NEF, Kemijoki OY and Hydro-Québec.

The credibility of the Annex III work has been greatly enhanced by the contributions from the participating experts representing: Ethiopia, Indonesia, Laos, Nepal, Philippines and Vietnam. Japan and Norway supported their participation. All Annex III countries and companies are thanked for financing additional internationally renowned experts in specialized subject areas. This ensured that progress was maintained and credibility was enhanced.

I also wish to thank the professionals who have filled in the comprehensive questionnaires. The participation from the World Bank and WCD has inspired the Annex III team and contributed to the actuality of our results.

The Executive Committee members are thanked for their guidance, support and co-operation.

Even if all names are given in the review of the IEA-Annex III Organization in Volume III, appendix C, I would like to draw special attention to the following persons due to their active participation and support over the years: Mr. Jens Petter Taasen (Annex III secretary and STL 1), Ms. Kirsti Hind Fagerlund (Annex III secretary and STL 1), Mr.Björn Svensson (STL 3), Mr. José M. del Corral Beltrán (STL 4), Ms. Cristina Rivero (STL 4), Mr. Jean-Étienne Klimpt (STL 5), Mr. Gaétan Hayeur (STL 6), Mr. Serge Trussart (STL 6), Mr. Joseph Milewski, Mr. Frans Koch (Executive Committee secretary), Mr. Luc Gagnon, Mr. Raimo Kaikkonen, Mr. Hannu Puranen, Mr. Mario Tomasino, Mr. Shuichi Aki, Mr. Jun Hashimoto, Mr. Tsuyoshi Nakahata, Mr. Kiyoaki Uchikawa, Mr. Yohji Uchiyama, Mr. Svein T. Båtvik, Mr. Rune Flatby, Mr. Geir Y. Hermansen, Mr. David Corregidor Sanz, and Mr. Magnus Brandel.

Oslo 30 March 2000

Sverre Husebye, Operating Agent,
IEA-Annex III

PREFACE

The International Energy Agency (IEA) is an autonomous body, established in November 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD). The IEA carries out a comprehensive programme of energy co-operation among 24 of the OECD's 29 member countries. The basic aims of the IEA, which are stated in the *Agreement on an International Energy Programme*, are the following:

- cooperation among IEA participating countries to reduce excessive dependence on oil through energy conservation, development of alternative energy sources, and energy research and development;

- an information system on the international oil market as well as consultation with oil companies;

- cooperation with oil producing and oil consuming countries with a view to supporting stable international energy trade, as well as the rational management and use of world energy resources in the interest of all countries;

- a plan to prepare participating countries against the risk of a major disruption of oil supplies and to share available oil in case of an emergency.

At its inception, the IEA concentrated on issues related to oil. Since that time the Agency has broadened its work to include all forms of energy. More than forty "Implementing Agreements" have been set up to deal with specific energy technology issues. Such Agreements comprise a number of task forces, called "Annexes", which implement specific activities such as collection of data or statistics, assessment of environmental impacts, joint development of technology etc. The work of these Annexes is directed by an "Executive Committee" consisting of representatives of the participating Governments.

In 1995, seven IEA member countries agreed to co-operate in a five-year research program focused on hydroelectric power formally called the *Implementing Agreement for Hydropower Technologies and Programmes.* Italy withdrew, but France, United Kingdom and People's Republic of China subsequently joined the remaining countries. This Agreement proposed that four distinct Task Forces (Annexes) should be set up to address the following topics:

Annex I:
Upgrading of Existing Hydropower Facilities

Annex II:
Small-Scale Hydropower

Annex III:
Hydropower and the Environment

Annex V:
Education and Training

Annex III "Hydropower and the Environment" entered into force in February 1995 with the following principal objectives.

- To arrive at a set of international recommendations for environmental impact assessment of hydropower projects, and criteria for the application of mitigation measures.

- To improve the understanding of hydropower's environmental advantages and suggest ways to ameliorate its environmental drawbacks.

- To forward national experiences regarding environmental effects of hydropower development at a project level and the legislation and decision making process at a national level.

- To provide an environmental comparison between hydropower and other sources for electricity production.

To achieve these goals the following Subtasks have been implemented:

Subtask 1:
Survey of the environmental and social impacts and the effectiveness of mitigation measures in hydropower development *(Subtask leader: NVE, Norway)*

Subtask 2:
Data base (included in Subtask 1)

Subtask 3:
Environmental comparison between hydropower and other energy sources for electricity generation *(Subtask leader: Vattenfall, Sweden)*

Subtask 4:
Survey of existing guidelines, legislative framework and standard procedures for environmental impact assessment related to hydropower development *(Subtask leader: UNESA, Spain)*

Subtask 5
Present context and guidelines for future action *(Subtask leader: Hydro-Québec, Canada)*

Subtask 6
Efficiency of mitigation measures *(Subtask leader: Hydro-Québec, Canada)*

From a scientific perspective, environmental studies are complex because of the many interactions in the ecosystem. In a subject area as wide as hydropower and the environment, it has been important to maintain the scope of the work within the limits imposed by the five-year time schedule and the available financial and human resources. However, several of the topics discussed are very extensive and complex, and as such, ought to have been handled with resources equivalent to an Annex. The main Annex III challenges have been to define the context and focus on the most important environmental and social issues. Two guiding themes have been the relation to government decision-making processes, and the need to ensure the highest possible level of credibility of the work.

Annex III is based on a case study approach combined with experience from a wide range of international experts representing private companies, governmental institutions, universities, research institutions, and international organizations with relevance to the subject. In all 112 experts from 16 countries, the World Bank (WB) and the World Commission of Dams (WCD) have participated in meetings and workshops. Additionally, 29 professional papers have been presented at the meetings. The participating countries are responsible for the quality control of the information given at the national level. Reference groups have been consulted in some countries.

Like all extraction of natural resources, the harnessing of rivers affects the natural and social environment. Some of the impacts may be regarded as positive; others are negative and severe. Some impacts are immediate, whereas others are lingering, perhaps appearing after several years. The important question, however, is the severity of the negative impacts and how these can be reduced or mitigated. The aspect of ecological succession is also of great interest. Through history, the ecosystems have changed, as a result of sudden disasters or more gradual adjustments to the prevailing weather conditions. Any change in the physico-chemical conditions seems to trigger processes that establish a new ecological equilibrium that matches the new ambient situation. Under natural conditions environmental change is probably more common than constancy. Ecological winners and losers, therefore, are found in natural systems as well as those created by man.

Even if the "fuel" of a hydropower project is water and as such renewable, the projects are often quite controversial since the construction and operation directly influences the river systems, whereby the adverse impacts become direct and visible. The benefits, like avoidance of polluting emissions that would have been the unavoidable outcome of other electricity generating options is, however, less easily observed.

Access to water and water resources management will be a very important environmental and social global challenge in the new century, because water is unevenly distributed and there are regional deficits. Dam construction and transfer of rivers and water abstraction are elements in most water management systems. The lessons learned from past hydropower projects may be of great value in future water resources management systems. If a regional water resources master plan or management system is available, then the development of hydropower resources could also contribute to an improved water supply for other uses.

It is necessary to underline that the Annex III reports discuss the role and effects of hydropower projects and how to improve their sustainability. They do not consider the increased energy consumption *per se* since this aspect is a national and political issue. Annex III has developed a set of international recommendations and guidelines for improving environmental practices in existing and future hydropower projects. One main conclusion is the necessity of an environmental impact assessment undertaken by competent experts and forming an integrated part of the project planning.

The Annex III reports have been accomplished based on a cost and task sharing principle. The total costs amount to USD 805 305, while the task sharing part had a budget of 93 man months.

The reports which have been completed include 4 Technical reports (Subtasks 1, 3, 4, 6) with Appendices, one Synthesis report (Subtask 5) with Appendices and one Summary report presenting the recommendations and guidelines.

Annex III comprises the following countries and organizations: Canada (Ontario Hydro, 1995-98, Hydro-Québec 1995-2000), Finland (Kemijoki OY 1996-2000); Italy (ENEL 1995-98); Japan (CRIEPI 1995-2000); Norway (NVE 1995-2000); Spain (UNESA 1995-2000) and Sweden (Vattenfall AB 1995-2000).

Oslo 30 March 2000

Sverre Husebye
Operating Agent
IEA-Annex III

INTRODUCTION

This report builds on professional experience in managing environmental impacts of hydropower. It reviews processes and conditions which make hydroelectric projects environmentally and socially acceptable, identifies international best practices, and proposes a set of recommendations on hydroelectricity and the environment.

Trends in Global Electricity Demand

Over the last 22 years, global electricity production has more than doubled[1] and electricity demand is rising rapidly around the world as economic development spreads to emerging economies. Not only has electricity demand increased significantly, it is the fastest growing end-use of energy.[2]

Predictions for future electricity demand tend towards continued addition of generation capacity, particularly in developing countries, where most of the growth is concentrated. Nevertheless, predictions are inherently fragile as historical trends are used to predict future demand, even if the future rarely reproduces the past.[3]

Even if predictions are fragile, basic trends such as world population increase, continued urban migrations and urban growth in less developed countries[4] and associated food, water and health requirements all point towards increased power demand. Although more efficient use of electricity can slow down the rate of increase of demand, increased global demand is still inevitable, barring a prolonged global economic recession.

In summary, as developing countries and the international community strive to increase global prosperity, additional electricity generation is unavoidable in the medium and long term.

Beyond the additional demand generated by economic growth, there are close to 2 billion people without electricity today[5] due essentially to widespread poverty. This means no electric light, little or no refrigeration or communication appliances and often no running water. This situation is difficult to accept from an ethical standpoint.

Rural communities form a significant proportion of the unserviced population, and the means to provide rural electrification include both local electrical services, possibly based on renewable generation, or connection to the national grid. Greater access to electric power will also create much needed increase in employment opportunities in poor rural areas. Development cannot be sustained without energy, and electricity is one of its key forms. *Electricity is an essential tool to provide elementary services, currently denied to a huge number of people throughout the world.*

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1 International Energy Agency (IEA), 1995. *Key World Energy Statistics.* "*1973 and 1995 Fuel Shares of Electricity Generation*". In 1973, year of the first oil shock, total global electricity generation amounted to 6119 TWh; by 1995, it had increased 116% to 13204 TWh.

2 According to the US Energy Information Administration (US EIA), "Electricity is expected to remain the fastest growing form of energy end-use worldwide through 2010.(...) The growth of energy consumption worldwide is expected to continue at an annual rate of 2.0% from 1990 through 2010". In *International Energy Outlook* 1995: Electricity.

3 Energy forecasters probably did not anticipate the oil shock of 1973, or for that matter the Great Depression, two events this century that had dramatic effects on electricity supply and demand. See: Robert Skinner. 1995. *Global Energy Trends and Environmental Implications. in Energy and Environment,* vol.6, 1995, Issue 4. p. 263-282.

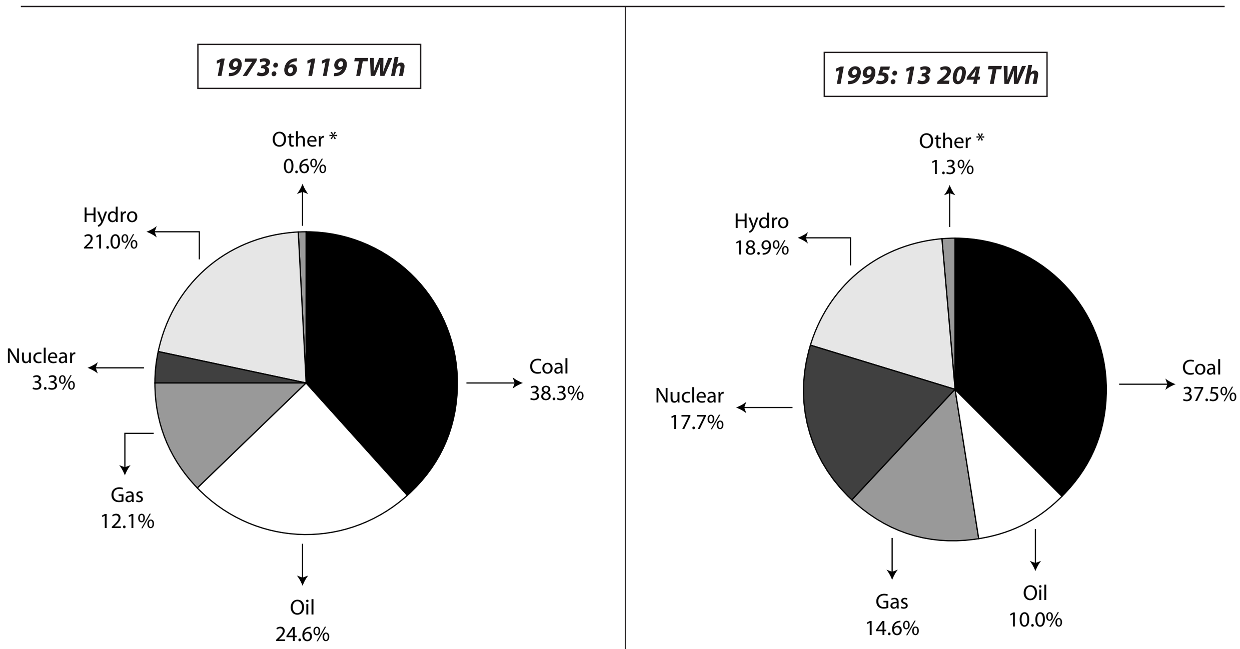
4 World Bank Technical Paper No. 220. Managing Urban Environmental Quality in Asia. See table 1.2 Urban Population Growth, 1960 – 2020, p. 12.

5 The World Bank. 1996. *Rural Energy and Development: Improving Energy Supplies for Two Billion People.* World Bank: Washington, DC.

Global Share of Renewable and Non-Renewable Electricity Sources

Most of the electricity produced worldwide comes from fossil fuels[6], among which coal (56% of electricity in the USA[7], 69% in China[8]) is the most important source. (see Figure 1, below).

Figure 1: ***1973 and 1995 Fuel Shares of Electricity Generation, Worldwide***



Source: *Key World Energy Statistics from the International Energy Agency (IEA).*
** Other includes geothermal, solar, wind, combustible renewables & waste.*

In 1995, coal, gas and oil represented 62.1% of the global fuel share in electricity generation, hydropower provided 18.9%, nuclear 17.7%, and "new renewables" altogether only 1.3%.

The major change in fuels for electricity generation over the last 22 years has been the displacement of oil (-14.6%) by nuclear power (+14.4%). Apart from hydropower, the other renewable sources represent a tiny fraction and will remain so for the near future.[9] *Today, most electricity is generated from the combustion of fossil fuels.*

Moreover, recent developments tend to indicate that nuclear power's continued expansion is threatened by public concerns, and that electricity generated from natural gas, a fossil fuel, is in increasing demand. If trends persist, *the predominance of fossil fuels, and thus greenhouse gas (GHG) emissions in electricity production will increase.*[10]

6 World Energy Council. Energy for Tomorrow's World.

7 US EIA. 1997. Table 8.1 Electricity Overview, 1949 – 1996.

8 US EIA. 1996. International Energy Outlook 1995: Electricity. http://www.eia.doe.gov/oiaf/ieo95/elect.html#ele01.

9 IEA, 1995. Key World Energy Statistics. (http://www.iea.org/stats/files/keystats/jsfrmset.htm).
If 20% of all new power plants were "new renewables" – an ambitious target –, their share in 10 years would still only be 4,7% (based on 2% annual growth in electricity demand, 1,3% share of "new" renewables in 1995, 13,204 TWh of total electricity generation in 1995). (Calculations by the author.)
See also: IEA, 1997. Electric Technologies. Bridge to the 21st Century and a Sustainable Future. p. 11.

10 Natural gas is the cleanest fossil fuel available for electricity generation. However, the combustion of natural gas results in substantial greenhouse gases (GHG) emissions. See: World Energy Council. *Energy for Tomorrow's World.* See also Ch.3 of this report.

Hydropower, a Major Alternative Source of Electricity Production

Hydropower, which is presently the only large scale renewable alternative to fossil fuel generation, provides approximately 19% of the electricity produced worldwide.[11] A total of 66 countries generate at least half of their electricity from hydropower[12] including large economies such as Brazil (97% of national electricity production), Canada (62% of national electricity production) and Norway (99% of national electricity production).

Worldwide, only about one third of the economically feasible potential of hydropower has been developed.[13] Furthermore, there are over 300 dams 60 meters or higher under construction at the present time (1998). China has over 70 such dams under way, Japan and Turkey over 50 each. *The potential for continued expansion of hydropower exists and is actively pursued by developers.*

Unlike other large scale means of electricity generation – fossil and nuclear – hydropower comes from a renewable resource, the water cycle. The damming of rivers, usually at sites where the water level can be raised substantially, provides the kinetic energy to produce electric power. Given that electricity cannot as yet be stored in large amounts, water is often stored behind dams[14] to provide a reserve of power that can be released on demand. Combined with the simplicity and flexibility of operating this technology, this makes hydropower a very desirable asset in electricity grid operations.

The damming of rivers to generate electricity transforms the local natural and human environment, by inundating land upstream and modifying the river flows downstream. *Though hydropower is the major source of renewable electricity production and as such provides major global environmental benefits, it also generates significant local impacts.*

Hydropower and its Impacts

Hydropower raises specific environmental issues, related to the transformation of land use and of river flow patterns. These issues vary substantially from one geographic context to another. Every hydropower plant has unique characteristics: It may be located in desert or semi-desertic ecosystems, in high mountain areas, in tropical forests, in agricultural valleys or urban areas. It may be in a populated or unpopulated area, it may have a large or small reservoir, or none at all. Examples of major concerns include involuntary population displacement, the flooding of natural habitats, or the threat of increased water-borne diseases in tropical countries, among others.

The case of involuntary resettlement is symptomatic of the challenges confronting hydropower development, and the analysis of its impacts. Resettlement is a very significant impact for certain specific projects, and must be managed competently and fairly. Otherwise, human tragedies may result, where people are dispossessed of their livelihoods, communities are uprooted and vulnerable populations dispersed. There are cases of such occurrences associated with various major public infrastructure projects – highways, urban development, power stations – including major dams. Nevertheless, many governments are convinced that with good resettlement programs these projects generate collective benefits, in terms of power, irrigation or other uses, which largely exceed the adverse impacts.

It is essential that the significant social impacts of involuntary resettlement must be avoided whenever possible, or properly dealt with when unavoidable. The challenge is to ensure that hydropower projects foster regional social and economic development by providing clear-cut benefits to local people, whether displaced or not.

11 *Op. cit.*. IEA, 1995.

12 International Hydropower Association (IHA). 1998. *The International Journal on Hydropower and Dams. 1998 World Atlas and Industry Guide.*

13 *Op. cit.*. IHA, 1998.

14 With the notable exception of run-of-river projects (see Ch.1 in this report).

As suggested in the previous example based on resettlement, the thrust of this report is to review past experiences in managing the environmental and social impacts of hydropower projects, in view of assessing the relative effectiveness of the tools available to avoid, or otherwise manage such impacts and propose recommendations to improve practices.

Hydropower and Water Management

Hydropower, by definition, requires fresh water[15], and although it does not use up the water, it still competes with other uses. Water is a fundamental life-sustaining resource for plants, animals and humans alike and as such provides important ecosystem services that cannot be replaced without a cost. It is also an essential element in communications, sanitation, industry and civilization. Abundant water for agriculture is required to sustain urban dwellers. Many great cities throughout history have developed alongside large rivers: Baghdad and the Tigris, Cairo and the Nile, Paris and the Seine, Bangkok and the Chao Phraya.

Fresh water is unevenly distributed on the planet. It is present in insufficient quantities in many regions of the world, and is overabundant in others. Where water is abundant it may still be degraded: deforestation in the upstream areas of watersheds, for example, may increase surface runoff and erosion, loading rivers with sediments and agricultural pollutants.

Fortunately, water is not as much "used", as it is "borrowed" or displaced. One may argue that the water we drink is the same the dinosaurs drank 100 million years ago, recycled and purified again and again. Most human water uses return the resource to the rivers, aquifers, oceans and atmosphere, although often in a degraded form.

However, pressure is rapidly increasing on existing watersheds, essentially due to the trebling of human population over the last 3 generations.[16] In 1990, 28 countries experienced water stress or scarcity. By 2025, the figure will rise to 50 countries and 3 billion people will be adversely affected, the majority in least developed countries. There is a need to reverse the trend whereby demand is outrunning supply of fresh water, while its quality is declining due to human abuse.[17] *Worldwide competition for water is increasing, rapidly.*

Faced with such daunting prospects, national and international organizations are developing frameworks for integrated water management.[18] These approaches stress the need for basin-wide, participatory management involving water users, planners and policy-makers. Hydropower projects and their dams are inevitably an important issue in such debates.

Hydropower, a Source of Environmental Debate

Hydropower is one of the many demands exerted on fresh water. Much of the environmental controversy about hydropower may be related to this fact, as it may be perceived as an extra "burden" on an already severely degraded resource. Unlike hydropower, the consumption of fossil fuels for thermal power generation actually "depletes" resources by burning the fuel, but the fuels used – coal, oil, gas – are not perceived as life-sustaining resources.

Hydropower, which was long seen as a "clean" and "renewable" way of generating electricity and regulating floods, is now often perceived, particularly in developed countries, as a "threat" to ecosystems and a net loss for the environment and society alike. The most vocal opponents to hydropower today are environmental interest groups[19], some of which recommend to stop building dams, and to dismantle some of the existing ones. Interestingly, the controversy often focuses on dams rather than

15 Experimental techniques are being explored to harness the energy from ocean currents (see: *EU Supports "underwater windmill" Sea Power Project,* in The Financial Times of London. Aug. 23, 1998), and a large tidal power station on the Rance river estuary in France has been in operation since the 1960's. Apart from such exceptions, hydropower is a fresh water technology.

16 The population today (1999) is 6 billion people, whereas in 1930 it was 2 billion. (ref. US Bureau of the census. International Programs Center.)

17 Organization for Economic Cooperation and Development (OECD) Work Programme on Sustainable Consumption and Production, Highlights of the Workshop on Sustainable Water Consumption Sydney, Australia, 10-12 February 1997 (http://www.oecd.org/env/sust/water.htm).

18 *The Dublin Statement on Water and Sustainable Development.* United Nations. 1992. International Conference on Water and the Environment. See also: *Water Resources Management. A World Bank Policy Paper.* p. 45-46 World Bank. 1993.

19 Well-known critics of hydropower are, for example, the International Rivers Network (http://www.irn.org), the Environmental Defense (http://www.edf.org) or the Natural Resource Defense Council (http://www.nrdc.org), in the USA. Some environmental associations support hydropower as an ecologically responsible mode of electricity production such as the GRAME (http://www.grame.qc.ca) in Canada.

hydropower as only a relatively small proportion of large dams throughout the world (20%) are used for the production of electricity, while a much larger proportion of dams (48%) are built for irrigation purposes only (Robert Lecornu, ICOLD, 1998). Much has been written lately in the media, academic circles and activist organizations about such issues.

Where does the truth lie? Is hydropower a setback or a blessing, in environmental terms? Are all hydropower projects the same? What are the ethical issues involved in developing hydropower? What is the real nature of environmental impacts associated with hydropower? Can they be sufficiently mitigated or not? These are some of the questions many organizations are grappling with[20], including both proponents and opponents of hydropower. *This report aims to provide the reader with a practitioners' perspective regarding some of these issues.*

The contents of the report are summarized below.

Purpose and Contents of the Report

The purpose of this report is to present in a systematic way a critical review of environmental practices and decision-making in the hydropower field. It is written by practitioners[21] *in view of improving future projects.*

Before presenting the technical issues, *chapter 1* begins by discussing the nature of hydropower: What are the different types of projects and what levels of service[22] do they provide?

Chapter 2 explores the present context in which hydropower evolves. It addresses recent trends in hydropower development, such as the growing role of private enterprise and the recent technical advances in this field, as well as the potential consequences of such trends on environmental activities.

What are the environmental impacts of available electricity production alternatives? *Chapter 3* tackles this question, by summarizing the state of knowledge in this field. The discussion is based on a "cradle to grave" evaluation of the impacts of the main generation options, better known as "life-cycle analysis" (LCA).

A critical summary review of the physical, biological and social impacts and mitigation measures[23] associated with hydropower is given in *chapter 4.* Best practices are exemplified and the efficiency of mitigation measures are discussed. A more detailed description of impacts and mitigation measures is given in Volume III, Appendices D, E, F, G of the present report.

Chapter 5 discusses the resolution of social conflicts that may arise in hydropower development. Ethics provide useful insights on how conflicting opinions within society can be addressed and resolved.

Chapter 6 integrates results of the survey carried out on the existing regulatory and legal contexts.[24] Its objective is to compare legislative and administrative processes in various countries, in order to identify problems and best practices. Best practices, here, are defined as credible and efficient processes. Credibility and efficiency must be understood from both an environmental perspective – a process that is transparent, scientific, and that effectively protects the environment – and from a decision-maker's point of view – a process that is cost-efficient, rapid and clear, minimizing uncertainties.

Throughout this document and the supporting studies, the authors have tried to identify existing weaknesses in the process of designing, constructing and managing hydropower projects, from an environmental and social perspective. These weaknesses may be procedural, scientific or political.

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20 The World Commission on Dams (http://www.dams.org), for example, set up by the IUCN (http://www.iucn.org) and the World Bank (http://www.worldbank.org), is studying in detail many of the issues associated with dams in general.

21 The environmental specialists – geologists, biologists, ecologists, anthropologists, geographers, water and soil specialists and many others – who work in the hydropower field, for regulatory and government agencies, consultants, utilities, or academic institutions.

22 Volume III, Appendix A: Glossary. Some projects are better suited to provide peak load, or base load electricity. See also Ch.1: *Classification of Projects.*

23 IEA. Hydropower Agreement. 2000. Annex III. STIII/6 report "Hydropower and the Environment: Efficiency of Mitigation Measures".

24 IEA. 2000. Hydropower Agreement. Annex III. STIII/4 report "Survey of existing guidelines, legislative framework and standard procedures for EIA of hydropower projects".

Chapter 7 Summary and Recommendations builds on these shortcomings, and proposes a set of criteria and international recommendations which we believe may improve the design and management of projects.

The ultimate objective of such an exercise is to enhance the sustainability of hydropower by ensuring that existing and future projects satisfy the needs of the present generation without compromising available resources for future ones.

Method

The report is the result of a consensual approach. It reflects the points of view of professionals from varied backgrounds and organizations from seven International Energy Agency (IEA) Member countries. These professionals joined the IEA's Annex III Task Force on Hydropower and the Environment in 1995 in order to discuss the latest trends and developments in environmental practices related to hydropower. The Task Force brought together the varied professional experiences of the 20 or so participants, both in their own countries and in international projects.

The discussions between various industry and academic specialists were complemented by the preparation of detailed environmental questionnaires by various member country organizations. These questionnaires were designed to provide a broad perspective on worldwide experience in managing and mitigating environmental and social concerns associated with hydropower projects. The resulting database combined with the knowledge base developed in the organizations represented in the IEA's Annex III Task Force, are the basis of this report.

The organizations represented on the Annex III Task Force on Hydropower and the Environment are the following:

- Agency of Natural Resources and Energy, Ministry of International Trade and Industry (MITI), Japan
- Central Research Institute of Electric Power Industry (CRIEPI), Japan
- Directorate for Nature Management, Norway
- ENEL S.A. (until 1997), Italy
- Hydro-Québec (since 1997), Canada
- Kemijoki Oy, Finland
- Ministry of Petroleum and Energy, Norway
- New Energy Foundation, Japan
- Norwegian Water Resources and Energy Directorate (NVE), Norway
- Ontario Hydro (until 1997), Canada
- Swedish Environmental Research Institute, Sweden
- Unidad Electrica S.A. (UNESA), Spain
- Vattenfall, Sweden.

The views presented in this report do not necessarily represent the views of the above organizations.

Other contributors outside Annex III are listed in Appendix C of this report. A technical seminar held in March 1999 in El Escorial, Spain, brought together a broad spectrum of interested parties to discuss the key environmental and social issues associated with hydropower. Parties involved in the discussions included the following:

- Department of Energy of the Philippines, Mini-Hydro Division
- International Hydropower Association (IHA)
- Lapland Regional Environment Centre, Finland
- Swedish National Energy Administration
- The Swedish Association of Local Authorities
- The World Bank
- World Commission on Dams (WCD)
- Independent academic experts and consultants.

1 CLASSIFICATION OF HYDROPOWER PROJECTS

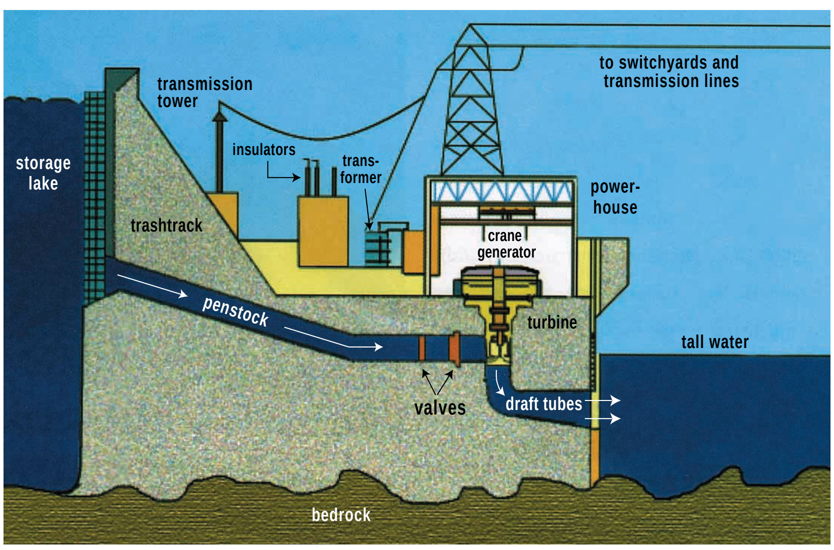
This first chapter briefly explains the nature of hydroelectric projects, commonalities and differences from project to project and what kind of energy supply each type of project provides. It gives an overview of the variety of projects built to generate hydroelectricity.

1.1 HYDROPOWER AND ELECTRICITY SUPPLY

Basically, hydropower takes advantage of the kinetic energy freed by falling water. In all hydroelectric generating stations, the rushing water drives a turbine, which converts the water's motion into mechanical and electrical energy. To produce electricity, the spinning turbine rotates a generator's electro-magnet (rotor) located inside a cylinder (stator) containing windings of electric wires. This basic hydropower unit is illustrated by the following figure (fig. 2).

Hydropower is the most efficient and reliable of all renewable energy sources. The simplicity of the process – absence of combustion, direct conversion of mechanical energy into electricity – explains the very high efficiency of hydropower plants. Hydropower plants typically operate at efficiencies of 85% to 95%.[1] This compares to about 55%[2] for combined-cycle gas turbines, 30 % to 40%[3] for coal or oil fired plants, 30%[4] for windpower and 7% to 17%[5] for solar photovoltaic panels.

Figure 2: ***Principle of a Hydropower Plant***



1 Department of Energy, Energy Efficiency and Renewable Network (EREN) http://www.eren.doe.gov/consumerinfo/refbriefs/tphydro.html.

2 Society of Energy and Resources, 1996. Handbook of Energy and Resources (Japanese), Ohmsha Co. Tokyo, Japan.

3 IEA, 1990. *L'énergie et l'environnement: vue d'ensemble des politiques,* p. 256.

4 Society of Energy and Resources, 1996. Handbook of Energy and Resources (Japanese), Ohmsha Co. Tokyo, Japan.

5 Department of Energy Photovoltaics, National Center for Photovoltaics wysiwyg://text.12/http://www.eren.doe.gov/pv/conveff.html

Figure 3: ***Example of daily change in electricity demand for nine electric power companies, 1975-1995, Japan***

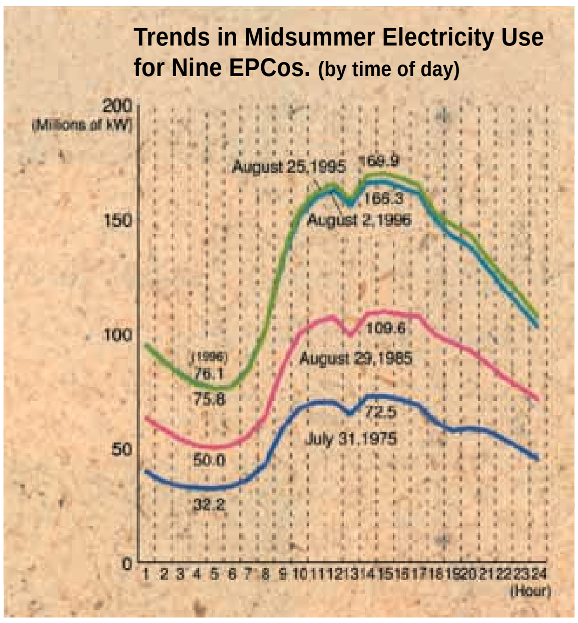
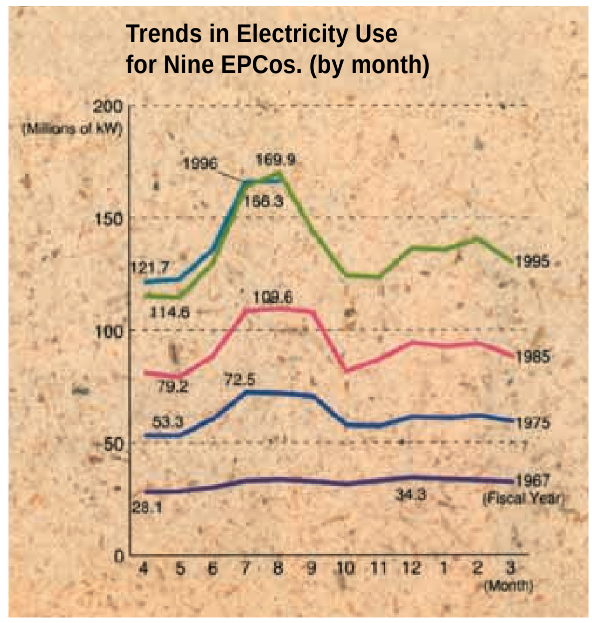


Figure 4: ***Example of annual change in electricity demand for nine electric power companies, 1967-1995, Japan***



Although electricity demand varies significantly during any given day (fig. 3) and throughout the year (fig. 4), electricity cannot be stored[6], unlike energy sources such as wood, petrol, or gas.

Electricity is characterized by the fact that production must match consumption. Electrons travel at the speed of light through power lines and therefore any change in electricity demand must instantaneously be matched by a equivalent adjustment in electricity generation. If demand increases and supply is not able to increase accordingly, then the voltage or "pressure" of the electric current drops, which can generate "brownouts" and stress on electric systems.

Thus, electric power utilities must ensure stable power supply at a lowest possible cost, to face the wide range of electricity demand. Utilities manage this constraint by combining diverse power plants which play a vital role in the electric power grid. System operators distinguish between base demand – or base load[7] – and peak load.[8] The base load corresponds to the fraction of the electricity

6 Energy can be "stored" in such as way as to release electricity rapidly: Electrochemical devices such as batteries will "release" electricity on demand. These devices are unable, however, to provide economical storage for electricity networks. Utilities must rely on storage of other forms of potential energy – such as fossil fuels or water behind dams –, readily transformed into electricity, in order to adjust to demand fluctuations.

7 Base Load: In a demand sense, a load that varies only slightly in level over a specified time period. In a supply sense, a plant that operates most efficiently at a relative constant level of generation.

8 Peak Load: The maximum electrical demand in a stated period of time. It may be the maximum instantaneous load or the maximum average load within a designated period of time.

demand which occurs regularly, throughout a given period; in contrast, the peak load corresponds to the surges in demand, beyond the base load, which occur at specific, usually predictable periods (for example, the evening peak load, when lighting and other electric appliances are put simultaneously into use by consumers). Some electricity generating plants are better suited to be operated as base plants, others as peaking plants. For example, nuclear power plants run optimally at a stable output, making them essentially base load generators. Hydropower plants in contrast may, depending on their design, provide electricity for base or for peak demand or both. This flexibility in energy supply is one of the specific technical advantage of hydropower.

Hydropower, then, may fulfill different electricity services.

- In regions where hydropower is very abundant (e.g., Norway 99%, Brazil 97%, Québec 95% of total electricity generation[9]), it satisfies both base and peak loads. The base load is produced by large or numerous reservoirs-type projects which store sufficient energy to cover several seasons of consumption and periods of dry weather, possibly combined, if available, with run-of-river plants. The peak load is generated by installing extra water turbines at certain power plants – additional capacity – that functions only a few hundred to a thousand hours a year during peak demand periods, providing the extra power.
- In regions where hydropower is not so abundant (France 15%, USA 10%, Japan 9% of total electricity generation[10]), utilities use other generation options which are not as flexible as hydropower. These require a relatively constant output to optimize production, (e.g., nuclear, coal, or oil thermal powerplants) to meet the base demand. Hydropower in this scenario is used both for base and peak needs. Commonly, reservoir and pumped-storage plants are used for peak demand and run-of-river plants for base demand. The type of projects best suited for this scenario are small reservoir plants[11], high head[12] run-of-river and pumped-storage plants.

This second strategy is far more common than the first, due to the limitation in available water resources, and points at another inherent technical advantage of hydropower: the capacity to generate electricity practically instantly, in 1 minute or less, from the moment the order has been given to start production. Hydroelectricity is, from a technical point of view, very complementary to other sources of primary generation, supplying highly reliable electricity[13], on demand.

In short, there are several different types of hydropower projects each having specific design characteristics, which enables them to serve particular energy needs and to supply different types of services. Obviously, each type of project produces also specific types and magnitudes of environmental and social impacts.

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9 ICOLD, 1998. IHA, 1999.

10 Idem.

11 Also known as *pondage*-type plants, e.g.,: run-of-river with a minor reservoir capacity.

12 Head: The vertical height of water in a reservoir above the turbine. The more head, the more power is exerted on the turbine by the force of gravity.

13 Due to the simplicity of design – no combustion, no steam cycle, no radiation protection – maintenance of hydropower plants is simplified and reliability is high.

1.2

TYPES OF HYDROELECTRIC PROJECTS

Hydropower projects can be classified in a number of ways which are not mutually exclusive[14]:

- by head (high or low), setting the type of hydraulic turbine to be used;

Photo 1: ***Tadami Power plant – a low head project in Japan***

Photo 2: ***Altadammen – a high head project in Norway***

Photo: K.O. Hillestad

- by storage capacity (run-of-the-river or reservoir projects);

Photo 3: ***Pesqueru – a run-of-river project in Spain***

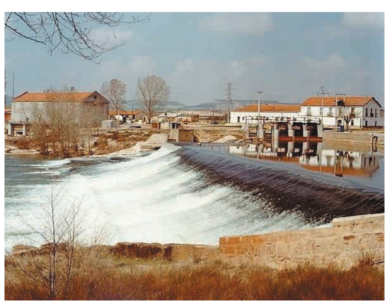
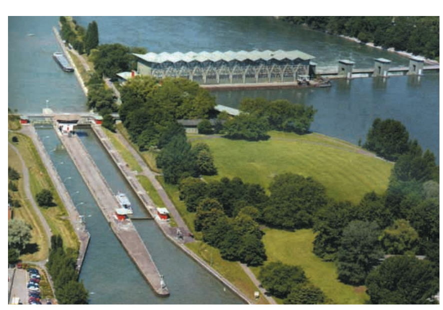


Photo 4: ***Orellana – a reservoir project in Spain***

- by purpose (single or multi-purpose);

Photo 5: ***Brisay – a single purpose project in Québec, Canada***

Photo 6: ***Freudenau – a multipurpose project in Vienna, Austria***



14 See for example: Alan Wyatt (WEC, 1986).

• by size (large, small, micro), and so on.

Photo 7: ***A large hydropower reservoir: Suvanto, Finland***

Photo 8: ***A mini hydro project: Kotaway in Indonesia***

The following sub-sections aim to briefly outline the energy services and the sources of environmental impacts produced by various types of projects. The proposed classification system will therefore focus on storage capacity. In addition, the different scales of a project will be considered.

Hence, hydroelectric projects can be categorized into two main types:

- *run-of-river-projects* (section 1.2.1) with little or no storage capacity, and

- *reservoir type projects.* (section 1.2.2) with significant storage capacity

Run-of-river plants generate electricity according to the available hydrological fluctuations of the site, whereas reservoir projects allow for a seasonal, annual or even multi-annual regulation of the water flow[15] and thus of electricity production.

Another specific type of project is called *pumped-storage*. This particular category will also be described below in section 1.2.3. The scale of projects is important when analyzing energy supply and environmental characteristics. Section 1.2.4 discusses *small, mini and micro* projects. The upgrading of existing hydropower schemes has environmental consequences and may modify the energy service provided by the plant. This issue is treated in section 1.2.5.

Furthermore, water flow may be increased by the construction of tunnels which collect water from an adjacent catchment area and feed into the river on which the project is located. In some cases cross-watershed collection and diversion may take place. These projects are usually called river *diversion projects* (section 1.2.6).

Finally, some projects are designed with several water uses in mind; these are *multi-purpose projects* (section 1.2.7) and will be addressed at the end of this section.

15 Examples of multi-annual storage reservoirs are: Lake Nasser on the Nile, Caniapiscau reservoir on the La Grande river in Québec, and the Lokka and Porttipahta reservoirs in Northern Finland.

1.2.1
Run-of-River-Type Projects

Description

This type of hydropower generation utilizes the flow of water within the natural range of the river. Therefore no or little impoundment takes place. Run-of-river plants are designed using large flow rate with small head – on large rivers with gentle gradient (photo 9: low head run-of-river), or small flow rate with high head – on small rivers with steep gradients (photo 10: high head run-of-river).

Photo 9: ***Kamaushi – a low head run-of-river power station in Japan***

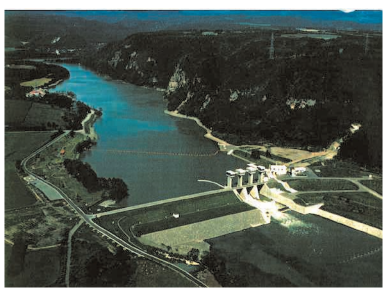


Photo 10: ***Nore power station – a high head run-of-river plant in Norway***

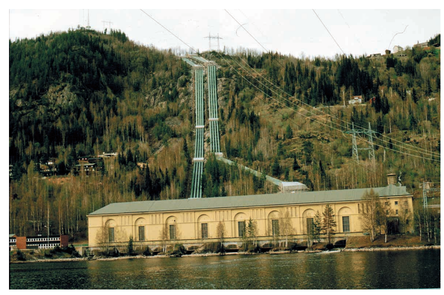


Photo: A.M. Tvede

a) *Low head run-of-river projects* tend to involve relatively small water retaining and other infrastructure, with turbines being anchored to the river bed. They are typically used for large rivers with gentle gradient .

b) *High head run-of-river projects* hydropower plants produce power more economically than low head schemes. Such hydro projects can be sited at water falls, as has been successfully done at the 2000 MW plant at Niagara Falls using a fraction of the total water flow at the site. In this case there is no impoundment, and the power house, penstocks and switchyard are underground. The tail race mixes in the natural plunge pool of the falls.

Energy Supply Characteristics

As a river flow changes through the year, corresponding inflow into the plant changes as well. To take in account this effect, multiple hydraulic turbines are set up to operate the power stations under such changing conditions or, alternatively, turbines with a mechanism that adjusts the amount of water required is used.

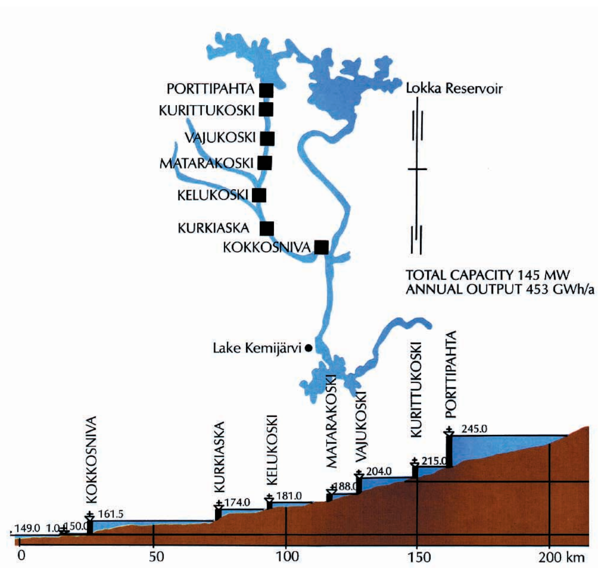
Consequently, the amount of power produced by run-of-river projects varies considerably throughout the year since it depends on the river discharge (photo 11). However, on a daily basis, it is normally operated at a constant output to supply power needed for the base demand.

The energy output of a run-of-river plant must also be looked at taking into consideration other power plants or dams upstream. It is quite possible to have a fairly constant output from a run-of-river plant if the river is already regulated by an upstream storage dam. A common strategy to optimize the energy output of hydropower plants on a river is to build a large storage reservoir in the upper catchment which will even out flows for several run-of-river or smaller reservoir plants downstream. (fig. 5)[16]

16 Source: Kemijoki Oy.

Photo 11: ***River flow and run-of-river production, Rivière-des-Prairies in Québec, Canada***

Figure 5: ***Cross-section of the Kitinen river in northern Finland***



Environmental Characteristics

Construction activities of run-of-river projects will tend to be less significant than reservoir project, reducing possible social impacts associated with the building of hydropower projects. The absence of any sizable reservoir helps limit considerably both the social and the environmental impacts, as the river is not transformed into a lake. This limits the flooding of land and therefore the potential resettlement of communities, and the disappearance of terrestrial ecosystems. Furthermore, the flow pattern of the river remains essentially unchanged, which reduces downstream impacts of the project.

In low head run-of-river, the small height difference between the water level upstream and downstream of the plant usually allows for the construction of fish ladders, as a mitigation measure for migrating aquatic species.

Run-of-river projects which divert only a small fraction of the river present significant environmental advantages when compared to projects which utilize all the river flow, as the former minimize the impacts on the original water body. However, high head run-of-river plants might require mitigation measures such as minimum ecological flow downstream of the river diversion to ensure sufficient water for aquatic habitats.

However, this environmental advantage is reduced if the comparison is made *per unit of energy produced* (kW/h): A project diverting only part of a river usually has less impacts on the environment, but also produces less electricity than a project on the same site using the full flow of the river. Therefore, based *on the equivalent amount of energy produced*, the environmental impacts might not be so different from one project to the other. This can be called the relative environmental impact (Impacts/kWh) of a power station.

1.2.2 Reservoir Type Projects

Description

Reservoir projects involve impounding water behind a dam to enable flow regulation throughout the year (on a daily or monthly basis) or even exceptionally on a multi-annual basis for very large reservoirs, providing a reserve of energy to satisfy electricity demand during dry seasons, and/or periods of peak demand. Reservoir schemes are typically used for highly variable flows in the middle reaches of a river, or as energy storage in the upper reaches of a river. Reservoir schemes on gorge or canyon systems are also desirable in view of the high output and efficiency that can be obtained.

Energy Supply Characteristics

Reservoir schemes offer a broader range of potential energy benefits than pure run-of-river schemes. The storage of energy is a fundamental asset of these projects. A reservoir such as Caniapiscau in the La Grande complex, Québec has a live storage capacity[17] of 39.6 km^3 (39.6 x 10^9 m^3) of water[18], equivalent to 48,8 TWh of energy or 28,7 million barrels of oil[19]. Beyond the energy storage function of reservoir projects, regulating a river in the upper watershed with a reservoir will increase the energy potential of sites downstream, as the regulated river will typically flow more evenly throughout the year. Thus, multiple run-of-river power plants may be developed downstream, in effect "re-using" the same water to produce additional electricity.

One can argue that in such a case not only is water a renewable cycle, it is also "re-cycled", producing electricity several times as it flows down river. For example, the La Grande river in Québec supplies half the electricity of the province, due to the very large upper reservoirs and the 8 hydropower plants downstream. The combined cascade of dams also allows to optimize power production, thereby reducing environmental impact relative to power production (impact / kWh).

Regarding size, reservoirs vary in area by a factor of a thousand, depending on the height of the dam, local topography and the desired energy service expected. Some reservoirs cover a few square kilometers, others 5,000 km^2 or more.[20] The variation in volume is even more pronounced. Planners design reservoirs according to its desired function: simply put, reservoirs can provide a seasonal storage capacity, annual or multi-annual. The latter provide the largest storage volumes and therefore energy security, but also, generally, the largest environmental impacts and certainly the most controversy.

Environmental Characteristics

The environmental impacts of reservoir type projects are best documented, and originate from:

- the construction activities involved in building the dam, embankments and power plant
- the presence of infrastructure
- the modification of river flow patterns
- the creation of a reservoir, possibly generating major ecological changes from terrestrial and river environments to a lentic environment, but also land-use transformations, such as resettlement of communities and of production activities.

The magnitude of the impacts will be a function of the site characteristics, and the size of the project. These specific elements above, will be discussed more in detail in Volume III, Appendices D, E, F of this report.

1.2.3 Pumped-Storage Type

Description

Pumped-storage plants pump water into an upper storage basin during off-peak hours using surplus electricity from base load power plants and reverse flow to generate electricity during the daily peak load period. It is considered to be one of the most efficient technologies available for energy storage. Appropriate siting, equipment and construction are particularly important in view of the high costs associated with pumped-storage system. It is important to identify cost-effective sites with higher head ranges, normally varying between 300 m and 800 m and relatively steep topography. Use of abandoned mines as the lower reservoir could be considered, such as the 1,500 MW Summit project in Ohio.[21]

17 Live storage: the volume of water between the bottom of the water intake of the powerplant and the maximum operating level of the reservoir.

18 Source: Hydro-Québec. 1995. *The La Grande Complex Development and its Main Environmental Issues.*6 p.

19 1 barrel = 1,701 x 10^3 KWh
1 KWh = 0,00058789 barrel
48 800 000 000 KWh x 0,00058789 = 28,7 million barrels. Source: *L'énergie au Québec.* 1998. Les publications Québec, Québec. p.107.

20 ICOLD (1998) World register of Dams, 151, boulevard Haussmann, 75008 Paris, 319 p.

21 The World Bank (http://www.virtualglobe.com/html/fpd/em/hydro/psp.htm).

There are two main parameters in the evaluation of costs of pumped-storage facilities: the ratio of waterway length to head (l/h) and the overall head of the project.

A low l/h will result in shorter water passages and will reduce the need for surge tanks to control transient flow condition. Higher head projects require smaller volumes of water to provide the same level of energy storage and smaller size waterway passages for the same level of power generation. In general, pumped-storage sites with high heads and low l/h ratio are more desirable.

Energy Supply Characteristics

Pumped-storage projects are designed to provide peak power during high demand periods. The concept of pumping water back to the upper reservoir during off-peak hours means that these plants are net energy consumers: it takes more power to pump water up to the top reservoir than is produced by the plant when the water rushes down to the lower reservoir. A pumped-storage plant produces a lot of power during short periods – a few hours, for example – but overall consumes energy, supplied by other power plants in the grid, in order to operate.

This drawback is balanced by the flexibility of operation of such plants and the low operating costs.

Environmental Characteristics

Pumped-storage plants are characterized by a small upper pool (often a few km^2 or less in size) which empties very quickly on short intervals (once or twice a week). The drawdown in the upper reservoir is therefore very significant. These pools are often man made and do not develop into a stable aquatic environment. The water in the upper pool comes from the lower reservoir and is returned to it. Pumped-storage plants sometimes can use a river, a lake or an existing reservoir as the lower reservoir. In other cases, a new reservoir must be created whose characteristics (i.e. draw-down, size) depend on the site's topographic and hydraulic conditions.

Photo 12: ***Numappara – a pumped-storage plant in Japan***

The environmental issues associated with the pumped-storage type plant are then mostly related to the siting of the upper pool, the powerhouse location (under-ground or above ground) and the nature of the lower reservoir ecosystem. These issues are essentially site-specific and can be addressed during the design phase of the project. (e.g., Lam Ta Khong 1,000 MW pumped-storage, EGAT, Thailand)

1.2.4 Small, Mini and Micro Projects

Description

These are definitions set in accordance with the difference in scale of relatively small hydropower generation in comparison with regular hydro-power generation. However, the definitions are relative and vary depending on the circumstances of each nation. Therefore, no definitions exist which are generally accepted all over the world. For example, China defines small hydropower as output not exceeding 25 MW.

Here for statistical purposes small, mini and micro hydropower are defined respectively as output less than 10 MW, 1 MW and 0,1 MW.[22]

The economical profitability of a small-scale plant depends like the large scale projects on site condi-tions. However, compared to large projects, it benefits in terms of ease of introduction, as the period for planning and construction is shorter and only small areas need to be acquired.

22 IEA (1999) Hydropower Agreement Annex II, personal communication.

As a number of sites available for the development of large scale hydropower is decreasing, concerned parties are now taking another look at small hydropower. Accordingly, efforts are underway to improve the economy of small hydropower by adopting more efficient designs and to review development plans.

Energy Supply Characteristics

This type of project can supply power to isolated where the power transmission system remains under-developed, such as rural areas in developing nations. Furthermore, it can serve as an isolated, local power source in order to improve standards of living, as well as it can be connected to an electricity network, providing thus the same type of service as other hydropower projects.

Environmental Characteristics

A frequently used and accepted rule of thumb is that environmental impacts are roughly proportional to area inundated.[23] It is generally assumed that the environmental impacts of small, mini or micro hydro projects are limited, given the scale of the projects, the limited intervention in terms of construction, and usually the small water bodies that are affected by the projects. There are also benefits related to reduced safety risks associated with small dams, and lesser population displacement or land use issues as a small project is easier to site. For example, this has led the states of Maine and New Jersey to consider small hydro which is defined respectively as plants of 30 MW and 100 MW or less as renewable and large hydro as a non-renewable energy ressource.[24, 25]

The Large Dam Versus Small Dam Debate

The large dam versus small dam debate is still unfolding. This debate has significant energy policy consequences (as mentioned above) and could also have serious implications for future hydropower projects. From an environmental standpoint, the distinction between renewable small dams and non-renewable large dams is somewhat arbitrary. It is not size that defines whether a project is renewable and sustainable or not, but the specific characteristics of the project and its location.

For instance, for an equivalent volume of water stored, geometry demonstrates that a small object has more surface area in proportion to its volume than a large object[26]; and the difference is quite significant. This implies that to obtain the same storage volume, the land mass inundated by 400 small hydropower plants of 5 MW would probably be anywhere from 2 to 10 times larger than the land mass inundated by a single 2000 MW plant. This means roughly 2 to 10 times the impacts on habitats to provide the same storage volume of a single very large reservoir. Table 1 gives a more precise estimate of the land area inundated for different sizes of hydropower plants.

Table 1: ***Average Size of Hydro Reservoir per Unit of Capacity*** [27]

Size of plants (MW)	Number of plants in category	Average size of reservoir per unit of power (ha/MW)
3000 to 18200	19	32
2000 to 2999	16	40
1000 to 1999	36	36
500 to 999	25	80
250 to 499	37	69
100 to 249	33	96
2 to 99	33	249

Source: Goodland, Robert,. 1995.

23 The World Bank. Environmentally Sustainable Development. Environment Department, Goodland, Robert (1994) *Ethical Priorities in Environmentally Sustainable Energy Systems: The case of Tropical Hydropower*, Environment working Paper p.3, 26 p.

24 Electric Discount and Energy Competition Act, New Jersey, adopted in February 1999.

25 Act to restructure the state's electric industry, Maine, Adopted in May 1999.

26 For example: doubling the volume of a cube increases the surface area by a factor of 1,59.

27 Goodland, Robert. *How to Distinguish Better Hydros from Worse: the Environmental Sustainability Challenge for the Hydro Industry.* The World Bank. 1995.

In addition, when comparing small hydro with large hydropower on the basis of equivalent electricity production then the environmental advantage of small over large hydro becomes much less obvious. What is less damaging for the environment? One very large power plant, on one river, with an installed capacity of 2000 MW, or 400 small hydropower plants of 5 MW on a hundred rivers?[28] Could the overall impact of a single 2000 MW project be less than the cumulative impact of 400 small hydropower projects of 5 MW, because of the number of rivers and tributaries which will be affected?

This is a theoretical question that cannot be easily answered, given the site specific nature of hydropower project impacts. However it illustrates the necessity of comparing the impacts of a human activity, such as hydroelectricity production, *in relation to the objective this activity pursues, that is, in this case, its power output.*

In summary, although it is obvious that a smaller human intervention on a specific habitat has less impacts than a very large intervention on the same habitat, one should compare hydropower projects based on the *energy and power produced.* From this standpoint, the cumulative impacts of a multitude of small hydro projects might be larger than those of a single project, given the diversity of ecosystems that will be affected and the much larger cumulative surface area to be inundated for equivalent storage volume with small projects.

Beyond the "small" versus "large" dams debate, specific site conditions and energy supply requirements are what determine the nature and amplitude of environmental impacts.

1.2.5 Upgrading Projects

Description and Energy Supply Characteristics

As hydropower projects are designed for a relatively long life-span[29], there is significant interest by power utilities in maintaining the outputs of their older hydroelectric stations since they are a source of cheap, flexible and often ecologically sound power. Indeed, upgrading capitalizes on existing facilities, costing less than new projects.

The options for extending plant life range from continued maintenance through various stages of *upgrading,* like *refurbishment, modernization and uprating.*

Refurbishment is generally aimed at returning the plant to close to "as new" condition and performance with a view to reducing ongoing maintenance costs and extending plant life by a specified period, typically 25-50 years. The net energy gain is usually small, if any, but extending plant life for 25 years or more will ensure reliable energy service for the future.

Modernization aims furthermore to improve plant availability through the use of more modern materials and technologies. This may provide efficiency in operation and therefore increased productivity.

Uprating however aims at expanding the plant's hydraulic capacity as well as the nominal power output measured in terms of megawatts (MW) installed. This kind of intervention may be considered for several reasons: first, uprating may be appropriate because of altered hydrological conditions. Second, changes in the plant's energy demand may require a shift in the plant operation mode from base load to peak load and entail uprating. Finally, uprating can present a solution to meet an increasing demand for power without burdening new environments.

Contrary to uprating, both refurbishment and modernization are upgrading activities which generally do not increase the power output significantly.

Environmental Characteristics

Optimizing the capacity of already existing facilities brings up much less environmental impacts than building up a new project, mainly because

28 The assumption here is that both scenarios will produce a similar amount of electricity, 10,500 GWh a year at a 60% load factor.

29 According to Whittaker and Topham (1991), the major components of the civil works are typically designed for a life approaching 100 years, while the major electro-mechanical components of hydroelectric schemes can expect operating lives of 50 years.

a reservoir is already present and available. The nature of environmental impacts related to upgrading activities is generally very concentrated in space and time as there is a strong economic incentive to minimize the length of any planned outages for carrying out refurbishment, modernization or uprating. Such projects therefore call for a high degree of planning and management both prior to and during the outage period, including environmentally sound working methods.

When the context requires a significant addition of power output, uprating projects may be combined with a river diversion development. From an environmental perspective, this solution may be more desirable than building a new hydropower scheme elsewhere.

1.2.6 River Diversion Projects

Description

River diversion projects consist of:

- *in-stream diversion:* diverting a river from its bed to take advantage of local topography. A river may be dammed and diverted through tunnels in the mountain-side to discharge further downstream back in its riverbed.This will decrease the river flow in the section of the riverbed between the diversion and the power plant tailbay, with a mitigation flow for ecological purpose provided.

- *cross-watershed diversion:* diversion of a river across a catchment and into another river. This strategy will increase the flow of the receiving river where the power plant is located, and decrease the flow of the diverted river, downstream. If the diversion is total, the downstream section of the diverted river will be dried up to the confluence with the nearest tributary.

Energy Supply Characteristics

The energy characteristics of the first type of river diversion projects is to increase the *head* of the power plant, thereby increasing the available power and energy.[30]

For cross watershed diversions, the result is similar: an increase in energy, this time by increasing the *flow* of the receiving stream, where the power plant is located.

Environmental Characteristics

The specific environmental impact of diversion projects is a severe or total reduction of flow immediately downstream of the diversion and, consequently, of water levels and water currents downstream of the river. This in turn may affect shore erosion, water temperature, water quality and an increase in retention time. The magnitude of the impact is a function of the ecosystems affected, particularly its aquatic biology, and the length of river with diminished flow. In cross watershed diversions, an additional impact has to do with the increased flow in the receiving river, with the reverse effects on water levels and currents. There is also a risk of spreading unwanted species, fish or plants, between catchments. Ultimately, a new ecological equilibrium appears, with colonization of the river edge by plants, shrubs and terrestrial fauna in diminished flow rivers, and an increase in water habitats in increased flow rivers.

The most effective mitigation measure, common nowadays, is to ensure a minimum ecological flow downstream of a diversion, to maintain a river habitat. This ecological flow may be designed based on the habitats of the most valued aquatic species in the river, in order to minimize the losses of spawning grounds, for example.

Engineering works can be designed in such a way that there will always be water available for the minimum ecological flow, particularly during long dry spells. With such a design, the water diversion stops if the water level in the reservoir does not reach the weir crest, whereas water remains available for the ecological flow, as it is drawn from the reservoir bottom. In the river with reduced flow, small weirs can be built to ensure a water level similar to pre-diversion conditions. (e.g., Eastmain-Opinaca complex, Québec and Kemijoki River, Finland)

30 Power = (flow) x (head) x (efficiency of the turbine-alternator) x (gravity).

Photo 13: ***Small weir in reduced-flow river, Norway***

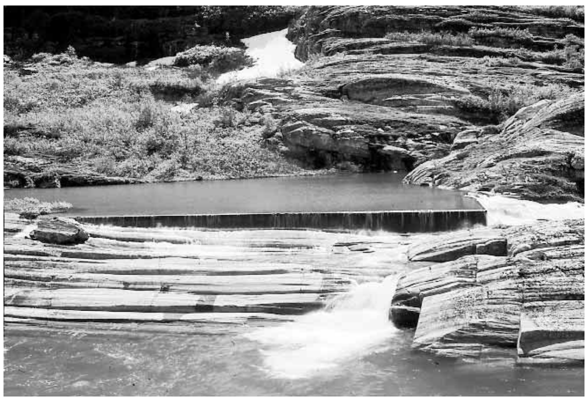


Photo: Mr. Birger Areklett

1.2.7 Multipurpose Projects

Description

In any of the projects described above, the water may be used for several purposes beyond power production. Increasingly today, projects are designed with several water uses in mind, and these are called multipurpose projects.

As hydropower does not consume the water that drives the turbines, this renewable resource is available for various other uses essential for human subsistence. In fact, a significant proportion of hydropower projects are designed for multiple purposes. Accordingly to Jacques Lecornu (1998) about the third of all hydropower projects takes on various other functions aside from generating electricity. They prevent or mitigate floods and droughts, they provide the possibility to irrigate agriculture, to supply water for domestic, municipal and industrial use as well as they can improve conditions for navigation, fishing, tourism or leisure activities.

One aspect often overlooked when addressing hydropower and the multiple uses of water is that the power plant, as a revenue generator, in some cases pays for the facilities required to develop other water uses, which might not generate sufficient direct revenues to finance their construction.

These different water uses impose conflicting demands on water utilization leading to trade-offs. Thus, this text aims to describe firstly the specific requirements of each type of utilization. Then, we will depict the consequences of multiple purpose projects on the energy supply capacity and discuss the major environmental issues associated.

Flood Mitigation

Dams for flood control have been built around the world for centuries prior to the advent of hydropower. By the means of dams and reservoirs the seasonal variations and climatic irregularities of the natural river flow can be regulated. The efficiency of flood prevention depends on the competent management of reservoir water levels and quality monitoring of precipitations in the watershed. The reservoir level is lowered prior to the anticipated flood, and fills up with the flood, absorbing and spreading its impact. However flood mitigation, with its requirement for empty storage space, imposes a significant constraint on other possible water uses, including electricity generation.

Irrigation

Water requirements for irrigation depend on the type of irrigation system, the kind of crop, and irrigation area. They usually vary seasonally (but remain fairly constant on an annual basis). The total water requirement consists of water needed by the crop and the losses associated with the delivery and application of the water. Variations in soil, climate, evaporation, or underlying geology can also greatly change the total water requirement. As irrigation withdraws water from the reservoir, it reduces the potential for hydroelectricity generation.

Municipal and Industrial Uses of Water

The demand for domestic, municipal and industrial water is largely influenced by present population and estimated future growth as well as by present and anticipated industrial uses. Municipal uses may be broken down into various categories, namely domestic, commercial, industrial and public. The factors that influence the uses are climate, characteristics and size of population centers, types of industry or commerce, water rates and metering. Requirements for municipal and industrial water tend to be more constant throughout the year than other functional requirements. In addition, maintenance of an adequate reserve to avoid water shortage during drought is necessary. The state of the water quality is a significant issue if the reservoir is supposed to supply drinking water. This could involve clearing the reservoir area biomass before the impoundment to prevent eutrophication and keeping up a reliable monitoring system during the operation period.

Navigation

The creation of a reservoir often makes waterways more suitable for navigation improving thus established transportation systems. On waterways where navigation is already a significant activity, dams and reservoirs are designed to allow boats to access and use the new bodies of water, through locks and channels, for example. Navigation may also develop as a new activity – for transport, fishing, recreation – in areas where it did not exist prior to the reservoir. Water requirements for navigation depend on the depth at critical locations in a waterway. Dams designed to improve navigation must be limited in height because of the need for locks. This requirement also constrains water storage allocations for other purposes.

Recreational Requirements

Recreational use requires a sound water quality and a sufficient seasonal reservoir level to permit boating, fishing, swimming and other activities. Recreational benefits are usually incidental to the other functions of the project, but may require particular shore developments and access facilities. Sanitary precautions for industrial and municipal use may sometimes preclude use of the reservoir for recreational purposes.

USA: The Office of Hydropower Licensing declares that there are over 28,000 tent/trailer/recreational vehicle sites, more than 1,100 miles of trails and 1,200 picnic areas linked to existing projects.[31]

Aquaculture

Recent experiences in Indonesia on the Saguling and Cirata reservoirs (Costa-Pierce,1998) show that planned development, enhancement, and management of capture ("fishing") and cage culture fisheries ("aquaculture") in artificial reservoirs can become an important food resource. These floating fish farms are based on a underwater cage system where young fish are fed until they reach a marketable size. Aside from an acceptable water quality, this activity requires a few shore access facilities as well as deep, sheltered bays. Fluctuations of the water level can be absorbed, as far as it doesn't fall below the critical minimum depth necessary to operate the floating systems.

Furthermore, there is the possibility of practicing wild fish management in the reservoir increasing its attractiveness for sport fishing. As the cold water in the deeper layers of the reservoirs constitutes an excellent trout habitat, in Tennessee[32], eight reservoirs and three smaller lakes are currently being stocked with trout providing interesting conditions for trout fishing. Elsewhere, in Finland[33], 7.4 million salmon, 1.9 million sea trout and 41.6 million migratory whitefish were stocked at the mouth of the River Kemijoki from 1983 to 1995. During the same period, 32.5 million local whitefish or grayling, 0.85 million brown trout and 1.4 million lamprey were stocked in various basins of the river.

31 Federal Energy Regulatory Commission (US), The Office of Hydropower Licensing, (1998) *Water Power, Use and Regulation of a Renewable Ressource,* http://www.ferc.fed.us/hydro/docs/waterpwr.htm.

32 Reservoir Trout Fishing – http://www.webfire.com/twra/resfishing.html. (1998).

33 Report on the results of fish management published by Kemijoki Oy, Finland, http://www.kemijoki.fi/ymkate.htm. Personal communication, Kemijoki Oy.

Indonesia: Costa-Pierce (1998) reports that in 1996 the total gross revenue from fish cage aquaculture was over US$ 24 million, over twice the estimated annual revenue ($ 10.4 million adjusted for inflation to 1996) from the 5,783 ha of rice lands lost to the reservoirs by the dams.[34]

Energy Supply Characteristics

Some types of multiple uses present more constraints to power generation than others. For example, irrigation, navigation, and water supply impose definite water demands, which require a clear allocation of storage space to each of the functional uses. Nevertheless, it is usually necessary to designate a certain amount of storage for power uses since the seasonal variation in power demand may not coincide with the demand for other uses, and, above all, since each type of power plant is designed to fulfill a specific type of energy demand.

Unquestionably, the type of energy supply required determines the compatibility of other uses. Hence a hydropower station destined to provide base load electricity, necessitates uniform water flow, unlike hydroelectric developments designed to satisfy peak demand.

Environmental Characteristics

The primary environmental characteristics of multiple use projects is the requirement to consider not only the environmental impacts of the hydropower project but also the cumulative impacts of all the other intended water uses. Obviously, the benefits of multiple use are various and important, as the undesired effects can be controlled by an adequate management (e.g., fishing licenses, programs to control the application of fertilizers and pesticides, etc.).

However, multipurpose developments makes planning and operating of hydropower more complex as it requires adequate coordination efforts with the various user groups and a sustainable water resource allocation. In fact, increased planning efforts may avoid a lot of problems caused by future unregulated uses of water. Thus, a balance must be found between divergent, and sometimes contradictory goals involving vast territories upstream as well as downstream of the river. An integrated Water Resource Management for the whole watershed must therefore be considered whenever multipurpose projects are foreseen.

The multipurpose nature of hydropower is unique to this form of electricity generation and demonstrates the importance of this activity in transforming a territory and the economic and social conditions of a population. All in all, multipurpose use of hydropower developments brings about major potential regarding electricity production, watershed management as well as enlarged environmental considerations due to the impacts associated with other water activities. It also bring major economic benefits, as a single reservoir is put to multiple uses.

1.3 CONCLUSION

Hydropower covers a wide variety of projects, from less than 0,1 MW (micro hydro) to over 10,000 MW, which corresponds to a 100,000 to 1 range. Projects also differ in their function, supplying base load or peak load, energy or power. These distinctions result in major technical differences – e.g., reservoir, run-of-river, multipurpose or pumped-storage type projects – which subsequently lead to widely different impacts on and benefits for the natural and human environments.

34 Costa-Pierce, B. (1998) "Constraints to the Sustainability of Cage Aquaculture for Resettlement from Hydropower Danms in Asia: An Indonesian Case Study" in *Journal of Environment and Development.*

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2 TRENDS IN HYDROPOWER DEVELOPMENT

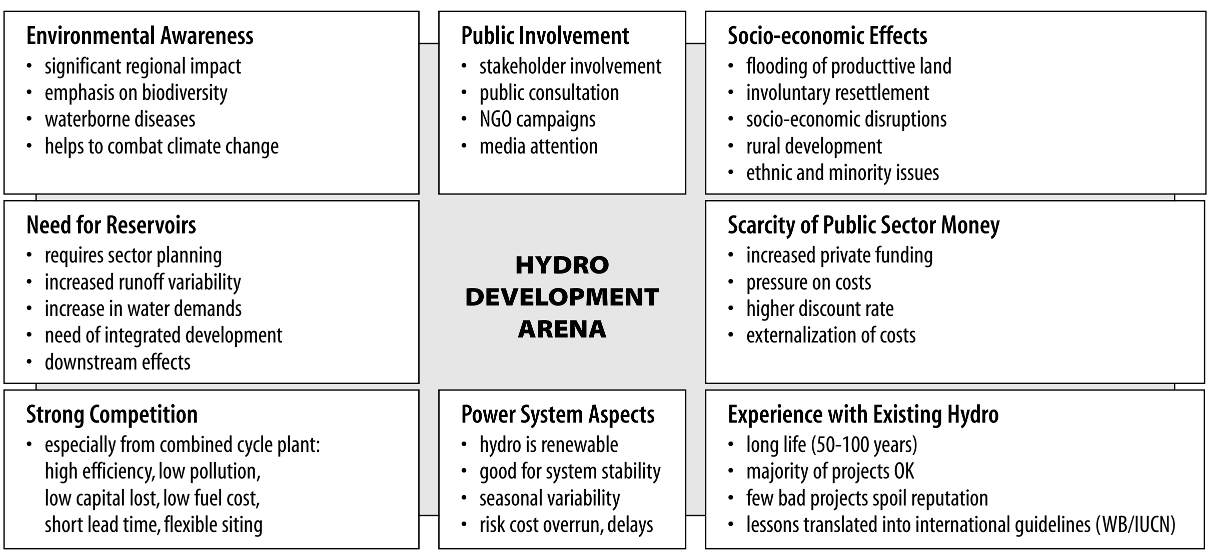
2.1
THE PLAYING FIELD

Hydropower development presently constitutes a controversial issue. Hydropower is also the only large scale renewable energy source which has established itself in the electricity sector.

If typical thermal generation had been developed instead of hydropower, CO_2 emissions from these thermal plants would be equivalent to emissions from about 750 millions cars, 1,5 times the current world fleet.[1] On the other hand hydropower projects may sometimes have a considerable environmental impact and may disrupt the lives of thousands of people.

The following figure illustrates the overall context under which hydropower development takes place.

Figure 6: ***Context for Hydropower Development***



This chapter identifies some trends in hydropower development. The planning and evaluation of hydropower projects is a complex issue and it is therefore difficult to 'isolate' individual trends. In this case it was decided to largely follow the project cycle, and identify trends in:

- restructuring of the electricity sector
- planning philosophy and procedures
- integrating Environmental Impact Assessment (EIA) into project and sectoral planning
- hydropower and global warming
- financial competitiveness
- project design, construction and operation.

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1 Evaluation based on following:
- 15,000 km/veh/yr, 8 liters per 100 km = consumption of 1200 liters/car/year
- motor gasoline = 2,36 t of CO_2/kL (Env-Canada) = 2,8 metric tons of CO_2/car/year
- World Hydro production: 2532 TWh (energy delivered)

Replacement scenario

60% coal	1 000 000 t/TWh
30% oil	850 000 t/TWh
10% nuclear	25 000 t/TWh

Average factor = 857 000 t/TWh (CO_2 equivalent) less life-cycle emissions from hydro = 30 000 t/TWh
Net avoided emissions: 827 000 t/TWh
World = 2532 TWh x 827 000 = 2 090 millions t of CO_2 equivalent/year; 2 090 Mt / 2,8 t = 746 million cars.

2.2

RESTRUCTURING OF ELECTRICITY MARKETS WORLDWIDE

2.2.1 Restructuring – A Global Phenomenon

Market restructuring is a worldwide phenomenon which has been under way in several economic sectors since the early 1980's. This movement is part of a process associated with the globalization of economic activity, the liberalization of trade and technological change. This process affects private as well as public companies, creating new markets and competition, replacing monopolies in such areas as telecommunications, natural gas, airlines, water supply and wastewater treatment, highways, electricity production, etc.

The rationale behind market restructuring is to ensure a more efficient allocation of resources, from an economic standpoint. However, such a process does create major structural adjustments to the economic sectors involved, with varied social and environmental consequences.

Beyond the economic justification for such restructuring, there are several underlying factors that drive the opening up of public utilities to market competition, among which:

- a redefinition of the role of the State in economic affairs, from a vision of the State as an active player in the economy towards that of a regulatory role of private markets
- the need for fresh capital investment in public utilities, when public finances are often in deficit both in emerging and developed economies
- new, cheaper technologies
- push towards market integration worldwide.

2.2.2 The Electricity Sector – Then and Now

The fundamentals of electricity markets have changed worldwide. The vertically-integrated electric utilities of the past, whether public or private, are rapidly being challenged by the competitive electricity markets being created in Europe, North America, Australia and New Zealand, as well as in many emerging economies.

In the past, governments granted utilities a territory where they often had a monopoly or near monopoly in the production, transmission and sometimes distribution of electricity. These monopolies were justified by the need for large-scale investments at a time when rural and urban electrification was expanding, when electricity demand was growing rapidly and economies of scale ensured lower unit costs from ever larger power plants.

The utilities were often created by nationalizing smaller private power generators. This frequently resulted at the time into significant reductions in electricity rates, as the expectations for return on capital from public utilities were lower than those for private investors. Moreover, economies of scale ensured a more efficient organization of power generation and transmission often allowing uniform electricity tariffs throughout vast areas. The creation of large public utilities allowed for the supply of electricity to remote or rural regions which were not considered profitable by private producers. Political considerations such as energy self-sufficiency were also a significant factor in promoting public utilities.

In the last two decades or so, the situation has changed dramatically: major power grids are completed, at least in developed countries, and growth in electricity demand has dropped to 1-2% a year. The monopoly status of public utilities and the emphasis on self-sufficiency has sometimes led utilities to overbuild, rather than taking advantage of the pooling and exchange of power resources with neighboring utilities.

A recent technological improvement, the combined cycle gas turbine, is also modifying the electricity generation business: where natural gas is inexpensive, this technology provides competitive electricity generation from small power plants often at a lower cost than what utilities may charge. This has led large industrial consumers to push for regulatory reform in the electricity business, to allow for self-production and freedom to purchase and sell electricity in an open market.

2.2.3 Characteristics of the Restructured Markets

The electricity sector generally consists of four main distinct activities:

- generation of electricity in power plants
- high-voltage transmission of electricity from the power plant to the consumer centers
- low-voltage distribution of electricity to each individual consumer
- business activity of trading electricity under short or long-term contracts between neighboring network, or between producers, retailers and consumers.

Under the traditional market structure, private or public utilities controlled one or more of these activities as regional monopolies. For example in France, Electricité de France has had up to 1999 a monopoly in generation, transmission, distribution and power exchanges throughout the country. In Japan, ten regional utilities control the electricity sector in their corresponding areas. In Canada, Hydro-Québec had up to 1998 a near monopoly over the electricity sector for the province of Québec.

The restructuring of electricity markets profoundly modifies these forms of organization. Over 70 countries are presently restructuring their power sector. These emerging markets share common characteristics. The main purpose of the on-going reforms is to make electricity a tradable market commodity, under the assumption that a free market will generate improved levels of service, including significant savings for electricity producers and consumers alike. The key issues are often similar.

- How to implement competition in electricity generation?
- How to ensure a non-discriminatory access to the power transmission grid?
- How to compensate for investments rendered non-competitive by liberalized markets? (stranded costs issue)
- To what extent customers are allowed direct access to producers and retailers? (wholesale or retail competition issue)?
- To what extent publicly-owned assets should be privatized?

The answers to these questions depend on the local context: the degree of openness varies according to the resources available in a region and the specific economic, social and political conditions in any given jurisdiction.

Generally speaking, the implementation of market reforms leads to the functional separation of the four main activities associated with the power sector: generation, transmission, distribution and sales. With market reforms, power generation is clearly separated from transmission and distribution. In addition, power exchange is opened-up to competing power trading companies.

Often, where monopolies existed, generation may be split up among several companies, with no single one able to control the local market. Transmission, on the other hand, is entrusted for technical reasons to a single company, called a "Transco" or "Gridco", usually independent of the power generators. The Transco has the responsibility of ensuring a free and fair access to all users to the transmission network. Distribution usually remains a local monopoly, for economic reasons, as it does not make sense to have various competing and parallel power distribution networks serving the same clients. The distribution companies may purchase its electricity from a variety of suppliers, whether power producers or power traders. A power exchange, similar to a stock exchange, is often set-up to allow traders, generators and consumers to buy and sell electricity, on a short-term (spot market) or longer-term basis.

THE NEW ELECTRICITY SYSTEM IN SPAIN

The new electricity system in Spain was implemented January 1st, 1998, following the Electricity Sector Act of 1997. The reforms are far reaching based on the following fundamental elements.

- Freedom to construct new electricity-generating stations.
- Competition among the electricity generating companies on a production market, based on a system of competitive electricity sales and purchase offers.
- Progressive freedom of the consumers to choose whichever supplier they prefer and to negotiate supply conditions and prices with this supplier.
- Freedom to commercialize electricity.
- Freedom of access to the electricity transmission and distribution networks.
- Freedom to buy or sell electricity from and to companies and consumers in other European Union countries.

Source: UNESA. 1997. Annual Statistical Report.

2.2.4 Consequences for Hydropower and the Environment

Restructuring and Hydropower

Most hydropower plants in the world are state-owned. Others are investor-owned, as many in the USA. Just about all of them were built under a system guaranteeing long-term and stable electricity contracts. These long-term contracts ensured that the capital borrowed to build the power plant could be repaid and provide an acceptable return on investment. The long-term stability in revenues was a key feature in convincing investors to build hydropower plants.

In a competitive market, this stability of revenues all but disappears, as electricity prices will fluctuate according to supply and demand. Given that hydropower plants require several years – sometimes decades – of careful planning and construction before producing any revenue stream, the added risk of fluctuating electricity prices will tend to favor other forms of electricity generation which are faster to bring on-line, at a lower initial capital cost than hydropower. For example, a combined-cycle natural gas power plant can be planned in a couple of years and built in 18 months at a lower capital cost than an equivalent hydropower plant. Wind turbines, although still expensive in capital investment, can be erected in 3 months.

Why then, from an economic point of view, build hydropower plants in restructured, competitive markets? The main reason is the exceptionally low long-term operation and maintenance costs, which often makes hydropower the most inexpensive source of power on the long term, combined with the numerous ancillary services provided by hydropower. Market competition in the electricity sector will certainly reward speed and flexibility in power plant construction and low initial capital outlays. In this respect new hydropower capacity will often be at a clear disadvantage as an electricity supply option.

Restructuring and the Environment

Assuming market competition will indeed favor short payback generating options such as combined-cycle natural gas plants, what are the environmental consequences of such a production shift?

The environmental consequences of a shift towards natural gas combustion for example, will depend on what technologies the new gas power plants replace. If natural gas displaces coal power plants, as in the USA or China where coal is the major fuel for electricity production, then the overall environmental impacts will be positive: gas combustion produces half the GHG and much less atmospheric pollutants than coal. However, if future natural gas power plants replace hydropower, as conceivable in Norway or certain regions of Canada, the global and regional environmental impact will be more severe. Natural gas combustion generates NOx emission and approximately 15 times more GHG than Nordic hydropower.

The environmental impacts of changing electricity generation options therefore depend on what technologies the new power plants will replace or displace. Because of the choice available in the production of electricity, it is the relative environmental impact of each technology which is significant rather than the absolute impact.

The development of renewable electricity options is another important environmental concern. Without specific government policies favoring renewable technologies, the only reasons investors will build renewable power plants in a competitive market is if renewables are cheaper to build than their non-renewable counterparts or if consumers are willing to pay a premium for such "green" electricity. Given that renewables are rarely the least costly production option – except for some hydropower –, their development in a free market will depend on the consumer's or the State's willingness to subsidize them. In short, a free market is "environmentally blind", as decisions are made purely on economic considerations, except if there are clear signals from governments or consumers to integrate environmental considerations.

The recent experience in marketing "green power" in the restructured Californian market has met until now with limited success. Private power marketers are faced with high marketing costs to promote environmentally friendly power and consumers do not seem very eager, for the time being, to pay a premium for lower impact electricity development.

FREE ELECTRICITY MARKETS AND THE ENVIRONMENT IN SCANDINAVIA

In the restructured market of Scandinavia, electricity trade between countries has significantly increased. By favoring lowest cost producers, the opening-up of electricity has stimulated the purchase by Sweden and Norway of inexpensive coal-based electricity from Denmark, to the detriment of less polluting indigenous sources of power.

This situation raises, among other questions, the ethical issue of avoiding most environmental impacts in one jurisdiction (Norway, Sweden) by importing power for elsewhere, where most of the pollution occurs (Denmark).

Source: Annex III participants.

2.3 TRENDS IN PLANNING

2.3.1 Old Approach

Until recently, the terms of reference for planning studies for large dam projects generally required a future demand (water, power) to be covered in a least-cost manner. The planning procedure was to develop alternative technical solutions, to select the least-cost option, and to mitigate the environmental and social impact of the plan or scenario to a minimum. 'Least-cost' was defined as the minimum present worth of investment, plus operating and maintenance costs over operating period, applying real term discount rates of 10 to 12 percent (in developing economies), and often ignoring external costs associated with residual environmental and social impacts.

In the industrialized countries some form of public discussion and feedback on design has been ensured through legislative and regulatory processes involving hearings. In the developing countries, however, decisions on development options have generally been taken in isolation by governments and utilities together with the international funding agencies, following the previously mentioned 'least-cost' approach.

The reaction to this techno-economic planning method has been the call for a more 'sustainable development' approach and to the formation of interest groups which wanted more attention to be paid to non-technical and non-economic issues. For a considerable time these groups, generally non-governmental organizations (NGOs) were seen as project 'opponents' seeking to obstruct development.

The more stubborn the reaction of the technocratic world to this opposition, the more spectacular became the opposition of the NGOs. This has been of course ideal food for the media and opposition politicians, and the result has been that many projects, in particular large infrastructure projects, stalled during the planning process as decision-makers and/or funding agencies did not want to be exposed to negative media attention. Painful examples from the recent past are the withdrawal of the development banks from large irrigation (India) and hydropower projects (Nepal).

Other large projects were implemented in spite of considerable opposition but often turned out to be no longer the 'least-cost' project as a result of costly delays and modifications during the implementation phase. Several nuclear power plants are a perfect example in this respect.

Disregard for civil rights of indigenous and rural communities by those in charge of decision making, often urban elites, and sometimes military or autocratic rulers, has sometimes led to flagrant violations of human rights during the planning and construction of large dam projects. The Operational Directives of the World Bank addressed this problem and have been instrumental in better protecting the rights of minority groups, reflecting the spirit of the new planning approach.

2.3.2 New Approach

Planning should avoid unnecessary expenditure and effort on projects which in the end will not be carried out. Planning procedures must therefore be geared toward maximized acceptance (or minimized regret).

To ensure broad acceptance of projects or system development alternatives, the new planning approach presents and discusses as early in the planning stage as possible all the pros and cons of competing scenarios with interested parties, including the persons directly affected by the project and NGOs, taking into account technical, economic, financial, environmental, social, institutional, political and risk factors. The interested parties jointly formulate a limited number of alternative plans to cover the future demand.

These plans should be diverse with respect to their impacts and should include plans featuring demand-side measures as well as the 'no-project' option, which often implies exploring alternative electricity supply options.

Subsequently, the necessary studies are done to quantify and evaluate the alternative plans in sufficient detail to be able to outline the consequences of each plan. Workshops are then organized in which all interested parties can discuss the results and try to reach consensus about the best plan to be adopted for implementation.

This approach requires a political and administrative frame within a country or region, that is able to coordinate and implement such participatory procedures. Promoters or opponents, alone, can hardly be expected to establish a level playing-field as they have strong interests in the outcome.[2]

This is a very 'democratic' approach, but one which may be rather novel and considered even as unacceptable in many countries, since decision-making is carried out at a political level without direct consultation of the people affected. Thus there may be limits as to how 'open' this kind of workshop can be made in practice.

2 Please refer to the discussion on Strategic Environmental Assessment (SEA) in Chapter 6 of this report, for more details on this issue.

The development banks should nevertheless pursue a policy which ensures maximum participation of project stakeholders, and if this is altogether rejected by a particular government, then the international funding agencies should refrain from becoming involved.

The major difference from previous planning practice is the attempt to reach a consensus of all parties concerned at as early a stage as possible, thus avoiding last-minute surprises after years of development expenditures, as has happened with several large dam projects in the recent past. Table 2 summarises the main differences between the old and new planning approach.

Table 2: ***Trends in the Planning of Hydropower Projects***

Old Planning Concept	New Planning Concept
A hydro project is a technical scheme to: • provide basic technical infrastructure to improve supply of power/water	**A hydro project is part of an integrated set of technical, environmental and social measures (e.g., Integrated Water Resource Management) to:** • cover basic needs of people in a sustainable manner (water, light, power, irrigation, flood control) through multiple use projects • accelerate rural development to improve the welfare of people in the region – particularly those directly affected by the project • improve environmental and flood protection • minimize GHG emissions.
Planning is government responsibility, often assisted by international development agencies	**Planning involves many partners/stakeholders:** • government • people affected • non-governmental organizations • private sector developers • financing institutions.
Least-cost planning procedure: • identify least-cost project to cover power/water needs • carry out unavoidable social and environmental impact mitigation at minimum cost • carry out detailed studies	**Multi-criteria planning procedure:** • project(s) must be part of sectoral development plan • rigorous study of project alternatives, including the No-Project option • prepare comprehensive comparison matrix showing pros and the cons of each alternative from technical, environmental, social, economic, financial, risk and political perspectives • quantify secondary and external costs and benefits as well as risk • reach consensus among stakeholders about overall best alternative to be developed • carry out detailed studies.
Public Sector Project: • developed and owned by government • funding partly from international development agencies	**Private/Public Sector Project:** • developed and owned by private sector, with or without government participation • financed largely from commercial sources • international development agencies act as catalyst for project funding by providing guarantees • access to semi-concessional funding if stringent international guidelines for social and environmental impact mitigation are followed.

2.4

INCREASED ROLE OF PRIVATE DEVELOPERS

With few exceptions, the development, ownership and operation of large dam projects in the past has been the responsibility of governments and national utilities. In industrialized countries such projects were financed from internal sources or balance sheet borrowings; in developing countries concessionary capital from multilateral and bilateral agencies was used.

In the last ten years irrevocable changes have occurred to this pattern. Governments everywhere are experiencing greater difficulty in raising finance for large infrastructure projects. This is particularly true of power sector investments which are increasingly being perceived as 'commercial'. In developing countries there has been an accompanying shift in concessionary lending priorities from physical infrastructure to social infrastructure. With an accelerating demand for power sector investment capital, the private sector has been encouraged to fill the gap through private sector financing and ownership.

Private developers want to limit up-front planning and preparation cost to a minimum and will try to shift or avoid as much of the costly design work to a point in time when financing of the scheme has been secured. Financial closure requires an accurate cost estimate and time plan for implementation. Public opposition could delay or even halt the implementation of a project and it is therefore in the interest of a proponent to select a project which can be assured of broad endorsement by the public but which may not necessarily be the 'least-cost' option. This can only be achieved through public consultation in the planning process.

Particularly in developing countries, private developers see themselves exposed to major political risks, e.g., the threat of nationalization or difficulties in converting local currency revenues into the hard currencies needed to repay the loans. The international development agencies may be willing to 'insure' the developers against that sort of political risk. This implies that the agency's operational directives need to be followed, particularly those dealing with environmental and social concerns.

The directives of the international development banks also call for public participation and consultation.

The emerging planning process for schemes funded by the private sector, but with involvement of the international development banks, appears to be as follows.

- Formulation of a limited number of diverse project alternatives including the 'no-project' option as well as the elaboration of environmental and social mitigation and compensation measures.
- Rapid analysis of these alternatives, considering technical, economic, financial, environmental, social, political and risk factors.
- Selection of the best overall solution through a consensus-seeking approach which involves all project stakeholders, including the people affected by the project as well as government and non-government organizations.
- Preliminary arrangements for project financing (memoranda of understanding with banks and development agencies, tariff negotiations).
- Project optimization and feasibility design, including elaboration of environmental and social mitigation and compensation measures.
- Financial closure (arrangement of project funding, final tariff negotiations).
- Detailed design, tendering and project construction, implementation of social and environmental action plan.

The change to private sector development poses still several questions.

- Will governments concerned have the ability and resources to negotiate appropriate terms and conditions with a fair sharing of benefits and risks?
- Will developers recognize the need for adequate social and environmental mitigation measures?
- Will there be sufficient time and investment to identify key problems or fatal flaws?

The increasing role of private sector development may lead to:

- an increase in new financing schemes, such as Build, Operate and Transfer (BOT), Build, Own, Operate and Transfer (BOOT), etc.
- more severe budget and time constraints
- more disciplined adherence to project schedules and budgets, as compared to public sector projects
- emphasis on financial project efficiency, resulting in reduced availability of time and funds for planning, investigation and construction work, and also an emphasis on cost-cutting operation and maintenance procedures
- less emphasis on sectoral planning
- externalization of the indirect costs associated with the project to the maximum extent
- levying of power (or water) tariffs which guarantee an attractive financial internal rate of return on the investment, these rates typically being higher than those projects financed conventionally in the past from grants and concessionary loans
- off-loading of as much risk as possible onto other parties, particularly onto the government.

It is clear that there is a strong need for adequate regulation and control in order to:

- maintain standards of safety and workmanship
- guarantee reasonable tariffs and government benefits
- avoid the government being exposed to undue levels of financial risk, and
- mitigate environmental and social impacts.

It goes without saying that the projects to be developed by the private sector must still be embedded into an overall water resources development plan for the country concerned and that the development of this plan similarly requires participation and consultation of the public on a wide variety of issues. Here governmental authorities can and should play a major role as well as international development agencies when their involvement is required.

2.4.1
Trends for the Financial Viability of Hydropower Projects

In countries with plentiful cheap natural gas, modern combined cycle plant can produce base load electricity at very competitive costs. Only the best hydropower projects can compete with this level of generation cost. In the industrialized world such hydropower opportunities are now rare, as the most attractive sites have already been developed, or cannot be developed for environmental or other reasons. In the developing world there are still quite a number of sites where hydropower can be produced at costs below 3 US ¢/kWh (1998).

However, the domestic demand in many developing countries is too low to warrant construction of these schemes. Energy intensive industries can only be attracted to these often remote countries if – in addition to cheap hydropower – there are good possibilities for, say, bauxite or iron or copper ore mining, if there is a stable political climate and if transport distances to the nearest markets are reasonable.

In regions where natural gas is not available in sufficient quantities, hydro competes often with coal-fired generation. Compared with gas, this introduces three additional factors: (i) the cost of coal, and (ii) the high capital cost of coal plant which depends to a large extent on the maximum unit size permissible in the system, and (iii) the considerable environmental impact of coal. A small 50 MW coal plant burning expensive coal, say at US$ 60 per ton, can produce base load electricity at a cost of about 6 US ¢/kWh, whereas a large multiple 600 MW unit burning coal of US$ 20 per ton can generate base load power at about 4 US ¢/kWh. There are many hydropower schemes which can compete with these prices, and given the environmental disadvantages of coal plants, hydro has here a winning edge. As the capital cost for coal-fired power plants is high, peaking energy will often be provided by either oil-fired gas turbines or hydroplants.

In remote places where fossil fuels are not available, or overly expensive, the generation cost of hydro may even exceed 10 US¢/kWh and it would still be able to compete, but more often than not the market will be only small.

Pumped-storage hydropower plants remain a viable option in power systems with a high daily peak demand, and with low-cost underused thermal or nuclear plants in off-peak hours.

Hydropower projects, and pumped-storage plants in particular, have substantial dynamic benefits in terms of system voltage and frequency regulation, ease of load following due to steep ramping rates, and more stable operation and longer life than thermal plants in the system.

Many highly industrialized countries have already developed most of their attractive hydropower sites in the past. The demand growth in the industrialized world has become almost stagnant and has dropped to a level below 2% per annum as result of:

- increasing efficiencies of electric appliances and lighting at the consumer level

- lower population growth.

High growth rates however are still observed in a number of rapidly developing countries, mainly in Asia, South and Central America, and Africa. Most of the world's hydropower development can be expected to take place in these tropical and subtropical regions.

Table 3: ***Competitiveness of Hydro***

Fossil Fuel Availability	Prospects for Base Load Hydro	Prospects for Peaking Hydro
Plentiful low cost natural gas	• Only if generation cost below 3 US¢ per kWh. Large cheap hydro may attract energy intensive industries, especially if required natural resources abundant and cheap. • Hydro may be attractive as incremental measure if dam built for purposes other than power generation.	• Only by increasing capacity of base load plant. • Otherwise gas-fired gas turbine more attractive. • Pumped-storage attractive if cheap base load available, particularly from nuclear powerplants.
Not sufficient gas, but coal available	• Hydro which can produce at less than 4 US ¢/kWh can compete. • For small systems and rather expensive coal even hydro with generation cost below 7 US ¢/kWh can be attractive.	• Viable if it can compete with oil-fired gas turbines. This is often the case for plant factor range between 10% and 50%, but not for standby duty and for daily peaking duration below, say, 2 hours/day. • Pumped-storage plant may be attractive.
Remote area with no, or overly expensive, fossil fuels	• Hydro with generation cost of up to 10 US ¢/kWh may be competitive. Market probably small.	• Peaking hydro is attractive, but some thermal standby (probably gas turbines) is needed to overcome drought periods. Standby plant may then also be used for peaking duties, competing with peaking hydro.

2.4.2 Emerging Conflicts Between Economic and Financial Planning

Economic planning has begun to internalize external cost in the planning process. External costs are economic costs borne by society, but are not reflected in tariffs. A good example here are penalties for emissions from thermal plants, such as CO_2, causing global warming, SO_2 and NO_X causing acid rain and PM_{10}[3] causing respiratory illnesses. External costs associated with large dam projects could, for example, be the loss of a major waterfall, the loss of biodiversity in the area inundated by the reservoir, the disappearance of migratory fish in the river due to the construction of the dam, and so forth. What the values are to be attributed to various external factors is not always clear in the absence of established procedures.

In the past, most of the electrical utilities were state monopolies, responsible for generation,transmission and distribution, often overstaffed with underpaid workers, which made them inefficient. Since about 1990 there is a tremendous drive to privatize electrical utilities world-wide, strongly promoted by the International Development Banks. In most power systems privatization goes hand-in-hand with unbundling of generation, transmission and distribution into separate companies.

The trend toward private-sector financing will inevitably lead to a reduced focus on economic optimality and greater focus on financial viability, i.e. the results of financial analysis will have greater impact on decision-making by the private sector than the results of socioeconomic analysis. Target rates of return for the private sector are, for projects in developing countries, often in the range of 15 to 20 per cent, equivalent to 12 to 17 per cent in real terms, even higher than the 10 to 12 per cent economic discount rate (opportunity cost of capital) which the development banks have typically been using for the planning of major infrastructure projects.

High discount rates do not support sustainable development, as the long-term damages or costs, associated with a project are simply discounted away. Moreover financial analysis considers only monetary cash flows, and external costs are not taken into account, again jeopardizing sustainable development. If, for example, certain fish species become extinct in a river downstream of a major dam, there is normally no financial penalty for the project operator, but costs are borne by society as a whole.

The conflict between economic and financial optimality will only be resolved if the developer obtains an adequate financial incentive to adopt the economically optimum solution. Mechanisms to let him switch, for example, from a coal-fired power station to a hydropower project, are still being contemplated, but could include:

- credits for avoided emissions
- tax incentives, especially for the early years of operation
- access to cheaper loans.

2.4.3 Improved Optimization of Projects in System Context

Large dam projects, particularly those producing hydropower, need to be optimized in a system context. This first of all means that in selecting the best dam sites, it should be kept in mind what the other developments in the river basin can be and how these affect each other. Secondly it means that the project should be optimized as part of the overall power system and not just be compared to a thermal plant of a particular type, which would often lead to too large projects. The systems analysis requires the use of complex hydro-thermal operation models, and the analysis of a range of alternative power system expansion plans, with and without the project, with and without demand side management measures, needed to select the overall best plan. The trends in system expansion planning are:

- Move from single- toward multi-objective models, away from deterministic least-cost optimization toward detailed multi-objective simulation. These detailed simulation models

3 Acronym signifying "Particulate Matter 10 microns or less".

produce an array of useful data, for example thermal plant emissions, risk indicators, employment figures, etc., which are relevant in selecting the best overall plan.

- Increasing use of chronological models even for long-term planning, using hourly time steps, rather than seasonal load duration curves, allowing more detailed simulation of system behavior.

- Improved simulation of the behavior of Independent power producer (IPP) projects, which try to exploit the power purchase agreement, and are not necessarily operated in 'merit' order.

- Models are increasingly able to simulate power pool arrangements, where several utilities cooperate in providing power to their consumers.

- Planning models are becoming 'financial' rather than 'economic' models, able to simulate commercial arrangements, and to predict the income, debt service and profit of individual plants extracted from the data generated by means of complex system operation simulations.

- System operation models are extended beyond the reservoirs to include the rivers and groundwater areas affected, considering both water quantity and water quality.

2.4.4 Improved Probabilistic Investment Analysis and Risk Avoidance Tools

The likelihood that a project becomes an economic or financial success depends to a large extent on the following factors:

- probability of cost over-run

- probability of delays during construction

- availability and value of water

- robustness of the water and/or power demand forecast, and

- probability of difficulties during the operation period.

These must be addressed in detail during the planning stage and nowadays excellent software is available to quantify the levels of risk associated with the development of hydropower projects (Oud and Muir, 1997).

The point here is that risk should be made transparent to the decision makers and stakeholders in order to allow balanced decision-making.

2.4.5 Decrease in Comprehensive Field Investigations

Comprehensive field investigations prior to construction is the cheapest way of risk avoidance.

However, due to the cost pressure on preparatory work, particularly in the case of private sector funded schemes where the developer does not have long term expertise in hydropower projects, there is a tendency to cut down on fieldwork. Topographic mapping, hydrological measurements and geological investigations are reduced to a minimum. This is a worrying trend. It should be mentioned that field investigations and sometimes outright production for other energy sources such as oil exploration or coal production frequently receive public subsidies under various forms[4], which is rarely the case for hydropower.

The hydrometric and meteorologic networks in many developing nations have deteriorated due to lack of funds even though good hydrological information is fundamental for the accuracy of benefit projections of water resources and other types of infrastructure development. Increased support of donor and funding organizations to expand existing networks, to include more sediment and water quality sampling, and to automate data collection and processing is necessary.

4 Organisation de Coopération et de Développement Économiques. 1998. *Réduire les subventions pour améliorer l'environnement. Partie II: Analyse et synthèse des études.* Paris: OCDE, 2 vols., p. 21

Comprehensive field investigations include the fieldwork required for environmental and social impact of the dam project, to identify mitigation measures, and to determine if they will work. The investigations need to be done before a final commitment is made to the project by the developer and the government as the study could find the project to be fatally flawed or to require inordinate mitigation measures.

2.5
ENVIRONMENTAL TRENDS

This section will point out three main environmental trends in the field of hydropower development. Firstly, an increasing integration of environmental assessment into the planning and design of a hydropower projects can be observed. Secondly, there is a significant trend to quantify environmental costs and benefits, and finally there is a growing recognition that hydropower is a tool against global warming.

2.5.1 Trend to Integrate Environmental Assessment (EA) into the Planning and Design of Hydropower Projects

In developed countries there is a strong trend towards the incorporation of environmental teams and environmental assessment into the planning and design of projects.

This is in recognition of the importance of environmental matters. The environmental team prepares the EIA which is usually debated in public hearings and subject to independent review by authorities, such as the ministry of the environment. The independent review process is an important component for public confidence in the EA process.

The integration of environmental and techno-economic studies allow for a much more efficient process, as the work proceeds in parallel rather than in sequence: Environmental problems may be identified and addressed early in the planning process rather than after the design work is completed. This way impact avoidance and mitigation becomes an integral part of the planning process.

2.5.2 Trend to Quantify Environmental Costs and Benefits

To facilitate comparison of alternatives, there is a tendency to try to translate into monetary terms as many environmental and social concerns as possible. Besides construction and maintenance costs for the technical hydropower scheme, the following, largely social and environmental cost and benefit categories may be distinguished:

2.5.2.1 Costs

Real Monetary Expenditures to Prevent or Reduce Impacts

Real monetary expenditures to prevent or reduce impacts which would be detrimental for the project or the affected population. Examples are:

- costs for erosion control in the upstream catchment to avoid excessive reservoir sedimentation
- cost for clearing the reservoir of biomass prior to impoundment to ensure a good water quality
- costs for a health care program to prevent the outbreak of diseases.

Costs in this category should be borne by the proponent.

Real Monetary Expenditures to Mitigate the Effect of the Impact.

Examples are:

- costs for compensation, resettlement, and community development programs
- provision of fish ponds or tanks, or another form of compensation, to communities living downstream of the river to make up for reduced fish catches after construction of the dam.

This category of costs is normally borne by the proponent.

Profits Foregone Due to the Construction of the Project

Examples are:

- value of a sustainable yield of timber which could have been extracted from the forest in the reservoir area. This is an external cost to society [5]
- the lost agricultural production potential
- lost opportunity to exploit mineral ressources.

These lost production values constitute a cost to the national economy, but usually does not constitute an immediate expenditure to the proponent.

The Costs of the Irreversible Loss of, or Threat to, Valuable and Rare Natural Habitats and/or Animal and Plant Species

These losses of valuable habitats and/or individual animal and plant species is a cost not only to the national, but also to the global economy, leading to increased scarcity and inherently higher value of remaining natural habitats (the 'stock' value of nature). The question here is how much the national and international community is willing to pay to keep precisely that habitat intact or, if that were cheaper, for the improved protection and management of remaining habitats of the same quality. This would constitute the real economic value, but it is hard to measure.

In cases where the project pays for improved protection of valuable habitats the net effect on the national and world economy are probably positive. For the project itself it constitutes a real cost, unless it 'boosts' the image of the project so much that additional concessionary financing from multi- or bilateral development agencies becomes available. In this case also the project itself will benefit.

2.5.2.2 Benefits

Avoided Thermal Generation Costs

These costs encompass:

- avoided construction, operation and maintenance costs of an equivalent thermal power plant
- avoided fuel costs and a slower depletion of the world's fossil fuel reserves (gas, oil, coal)
- avoided external costs of thermal plant emissions, which are responsible for air pollution, acid rain and global warming.

Secondary Benefits Due to the Construction of the Project

Examples are:

- rural development following construction of infrastructure and the availability of rural electricity
- prospects for irrigation and/or drinking water
- improved navigation in the receiving river
- the value of the products of lake fishery
- improved conditions for leisure and tourism activities.

These benefits usually do not accrue to the project entity, but can be substantial for the local and national economy, and the benefits are to a great extent real money values.

Tertiary effects exist and these may to some extent be quantified. If, for example, rural electricity becomes available, this may lead to a reduced use of charcoal with positive effects on the remaining forest, but negative effects on charcoal producers and traders.

Improved navigation can mean better marketing possibilities, better competitiveness of locally produced goods, increased trade, and so forth,

5 Usually the marketable timber in the reservoir area would be harvested prior to inundation, and the proceeds, in terms of Net Present Value, can be higher than that of a sustainable yield. The net cost to society may therefore be nil, or there may even be a benefit, depending on the discount rate used.

but can also mean increased exploitation and destruction of forest habitats because of better access and cheaper marketing of jungle produce.

2.5.2.3 To Whom the Secondary Costs and Benefits Accrue?

For example, there may be a net benefit for reservoir fishermen if the net fish catch increases in the reservoir. However, there may be a net cost for downstream fishermen, if their catches decrease. Consequently, the downstream population must be compensated.

From the perspective of the national or global economy there is, for most hydropower projects, an overall benefit: the secondary benefits outstrip the secondary costs, provided that proper impact mitigation is exercised. On the other hand, if no proper social and environmental mitigation is exercised, there will in most cases be an overall secondary cost.

Most monetary costs for environmental and social mitigation must be borne by the proponent and are incurred well before the project produces net benefits. It is important that proponents have adequate financial resources to start the mitigation programs before receiving revenues. It may be necessary to review project financing and taxation as proponents may have to make substantial investments in mitigation, besides having to meet construction costs, before receiving any revenues from the project. Most secondary benefits start to build up after completion of the project, and accrue to the economy, and the affected population.

Protection of nature and the world climate are a global benefit. The support of multilateral and bilateral aid agencies should be seen in this context. The provision of concessionary financing and institutional support for projects with good environmental and social mitigation can be seen, in part, as a pay-back of the global community for the protection of nature and the world climate.

2.5.3 Growing Recognition of Hydropower as a Means to Limit Global Warming

Especially in countries where the construction of hydro can prevent new coal-fired power plant, it is beyond doubt one of the attractive options to reduce GHG emissions, much cheaper than marginal efficiency improvements in highly industrialized countries. There is no doubt that Clean Development Mechanisms (CDM) will provide a stimulus for hydro.

Without the existing hydropower plants, the world-wide emission of greenhouse gases (GHG) would be some 11% higher than at present.

Hydropower projects also produce GHGs.

- Indirect during construction, from the use of fuel to operate the construction and manufacturing machinery, and from the use of fuel to produce and transport construction materials such as cement and steel. Generally speaking the amount of GHGs produced this way is offset by reduced thermal generation within a few months of operation of the hydropower project (Oud, 1993).

- Even if all biomass impounded by the reservoir would be fully 'burnt', the amount of GHGs released into the atmosphere is generally offset by reduced GHG emissions from thermal plant within a period of up to about 3 years (Oud, 1993). However, a large part of the biomass may be removed as timber for the construction and furniture industry. It may be argued that (i) much of the timber is transformed into durable goods, thereby storing carbon, (ii) the market for durable timber is not necessarily expanding, in other words: if extra timber comes from a reservoir area to be cleared, then approximately the same area will not be logged elsewhere.

- Measurements in Finland and Canada indicated that about 1% of the GHG emissions from reservoirs can be in the form of methane, but the studies do not state how much methane would have been emitted from the pre-impoundment forest land. Ignoring the pre-impoundment CH_4 emission, and considering that methane is a 21 times more potent GHG than CO_2, it may be concluded that methane adds generally not more than 20 percentage points to the GHG effect caused by CO_2 emissions.

It may be concluded that the GHG emissions caused by hydropower plants are offset by avoided thermal generation within a period of no more than 4 years in the case of major storage reservoirs inundating dense forest land, and in less than one year in the case of projects without reservoir. Given the long lifetime of 50 years and more, hydropower projects may therefore be considered as a major combatant in the fight against global warming.

Again, the support of multilateral and bilateral aid agencies in providing concessionary financing and institutional support for hydropower projects with good environmental and social mitigation can be seen, in part, as a pay-back of the global community for the protection of nature and the world climate.

2.6
TRENDS IN DESIGN

Whereas the previous section deals with trends in planning, the following sections deal with individual design aspects, which are almost all related to the desire to build large dam projects cheaper and faster. Some design changes are the direct result of increased awareness of environmental issues.

Another aspect is that of the need for involvement of independent panels of experts already during the design phase, particularly for projects financed by the private sector, to make sure that safety and workmanship meet internationally accepted standards.

2.6.1
Design of Hydropower Infrastructures

Reservoir

The trend is away from reservoirs which inundate relatively large areas of valuable land, major settlements, areas occupied by indigenous people or areas with unique habitats. Generally, there is a tendency towards smaller sized reservoirs. This could cause problems with sediment deposition in the reservoir itself, but reduce problems with upstream aggradation and downstream degradation. Multiple use of water is becoming more and more important. Reservoir clearing before impoundment is generally seen as necessary.

Dam

One of the major breakthroughs in dam construction has been the development of the roller compacted concrete (RCC) dam. The lower cement content and the mechanized placing of the concrete yield a relatively low unit cost of dam body, less than half the price of conventionally placed concrete. The RCC technique enables rapid placement; dams can grow by 60 cm (2 compacted layers) per day, making it possible to build a 200 m high dam in less than a year. Due to the lower cement content, less heat is developed during hardening, which is an added advantage. With RCC dams, river diversion during construction is often in-river, rather than by means of diversion tunnels. This also saves time and money.

So far only gravity dams have been built using RCC, but soon arch gravity and arch dams will make use of the same technology, using computer controlled infrared or radar guided construction machinery to obtain the right shape.

The RCC technology has made many dams feasible, which in the past appeared to be economically unattractive.

Another type of dam which has gained increased popularity is the concrete-faced rockfill dam (CFRD). Not only does it have a smaller volume than a rockfill dam with a central core or an earthfill dam, but an added advantage is that placing can continue even during inclement weather conditions, thereby reducing the cost and the risk of delayed completion.

Spillway

Spillway hydraulics are now better understood, particularly with respect to chute aeration requirements, and this has led to the use of higher specific discharges. This has had a cost-saving impact.

Scouring in the plunge pool area, downstream of the spillway flip bucket, is also now better understood and by ensuring a safe distance there is less danger of undermining the stability of the dam.

Better forecasting techniques and spillway monitoring can lead to improved safety. Flood warning systems and contingency plans for the downstream inhabitants can help evacuate people in a timely manner during extraordinary flood events. It is necessary to carry out flood zoning along the downstream river and delineate areas which will, be subject to, say, a once in ten-year, a once in hundred year, the design flood and a possible dam-break. Housing in the area subject to frequent flooding should generally not be permitted.

Water Intakes

The water quality and water temperature in the upper 10 to 15 meters of a reservoir are normally the best. There is a definite trend to variable-level intakes which allow water to be taken from the top layer, such as Kaeng Krun (Thailand) and Katse-Mohale (Lesotho).

Water Conduits

Tunnel-boring machines are becoming more attractive for various reasons: they allow construction of tunnels and inclined shafts of increasingly large diameters, they cut construction time and they are much more reliable than in the past.

The steel lining of underground pressure shafts is increasingly substituted by much cheaper heavily reinforced concrete lining, pre-stressed by means of pressure grouting after placement of the concrete lining.

Underground water conduits do not disturb the landscape, which makes them attractive from an environmental point of view. Surface penstocks, especially those with smaller diameters, are now sometimes galvanized in order to cut down maintenance cost.

In flat alluvial areas increased mechanization allows major cost reductions in the excavation and lining of power and irrigation canals, with substantially reduced water losses compared with unlined canals.

Powerhouse and Control Room

There is a tremendous drive to cut costs and manufacturing time of hydro-electrical equipment. This has led to increased employment of computer-aided manufacturing, a trend to welding rather than casting turbine runners, and to the design of low-maintenance equipment.

It appears that there is a trend to enlarge the head range which can be covered by Francis turbines, which have a cost advantage over both Kaplan (low head) and Pelton units (high head). For very large projects, unit sizes are becoming bigger to capitalize on the economy of scale.

Reregulating Pond and Fish Ladder

For dam projects with a peaking hydropower plant it is recommended to provide a re-regulating pond at the power outlet unless the project discharges directly into a downstream reservoir. Besides regulating the water so that it can be used for irrigation and will not cause damage to downstream boating and fishery, it sometimes has the added advantage that the water temperature can become closer to that in the natural river downstream.

When the outflow is regular and the head is low, fish ladders or by-pass channels may be effective. The trend is to avoid structures which obstruct fish migration and efforts are made to facilitate the upstream and downstream circulation of fish.

Irrigation Component

Large dams are often associated with major irrigation schemes, and lessons learned in irrigation affect the planning and design of large dams. Traditional irrigation systems often involved ‘recession’ i.e. the lands would be planted as the river receded after a flood and the irrigated lands would be subject to considerable variation in water levels during the year.

More or less constant river levels with barrages and/or pumping lead to more continuous irrigation. The water table rises, leading sometimes to waterlogging, and when water table is within reach of the surface, capillary action brings salt dissolved from the soil matrix to the surface.

Modern irrigation design incorporates surface and/or subsurface drainage to keep the groundwater table at a safe distance from the surface, and to carry away the saline drainage water.

Older irrigation systems tended to be inefficient, especially when featuring unlined canals and surface flooding. The general trend, especially in water-poor areas, is towards more efficient systems including sprinklers and drip-irrigation. Modern lining techniques for canals help to reduce the water losses. The increased efficiencies reduce the stored reservoir volume requirement and the amount of water lost to percolation.

Extensive use of modern construction machinery leads to efficient canal excavation and, using the same machine, immediate concrete lining with slipforms. Laser controlled earthmoving equipment facilitates the preparation of flat irrigation areas. This high degree of automation and mechanization cuts development costs and reduces time and cost over-runs.

High Voltage Transmission

High Voltage Direct Current (HVDC) transmission is becoming cheaper and permits efficient long distance transmission of large amounts of power, even if the electrical systems sending and receiving power are not synchronized. This may permit the construction of large, remote hydropower stations which serve distant load centers and may encourage regional and cross border transfers of electricity.

2.6.2 Design Tools

Refinement of Models

Enhanced finite-element analysis in, for example, rock mechanics, more detailed mathematical models for hydraulic and water quality simulations, and sophisticated, yet user-friendly computer-aided design software are now commonplace and allow the designer to work more quickly and yet more accurately. This is not to say that computer models replace experienced engineers, but rather that experienced engineers are able to work more efficiently and thoroughly.

Quantification and Consideration of Risk

Just like the models for economic and financial analysis, software used during the design phase is becoming more and more 'probabilistic', replacing 'deterministic' models. An example is the calculation of the risk of dam-overtopping, a potentially catastrophic event which could trigger the destruction of the dam. Here various events, each with their own probability, may be superimposed on each other.

Similarly, other factors affecting dam safety can be analyzed in a probabilistic manner, including the effects of earthquakes, internal erosion due to piping and/or foundation problems. None of these problems in isolation may be reason for a dam failure, but in combination they could be.

Visualization of Projects

The coming decade will see a tremendous drive toward visualization of the project, based on Geographical information system (GIS), Computer aided design (CAD) and animation techniques. This is increasingly important in an age where non-technical people have to participate in the decision-making process.

2.6.3 Design Work by Utilities, Contractors and Manufacturers

Increasingly utilities seek to expand internationally. They have excellent, but underused design teams, which can be used to carry out planning and design work for overseas projects in which the utility would like to invest.

In an era of privatization, there is also a trend for the detailed construction design, previously much the domain of international consultants, to be carried out by civil works contractors and equipment suppliers, particularly if they form part of the developer group.

2.6.4 Quality Insurance by Independent Panel of Experts

Particularly in an era of increased private sector involvement and the resulting time pressure on engineering, experienced and competent engineers are recruited to examine the design of large dam projects. The importance of quality assurance by a panel of independent experts in reviewing the design and safety of all project structures during the on-going design stage cannot be overemphasized.

2.7

TRENDS IN CONSTRUCTION

2.7.1
Overall Project Management

As a result of the increasing cost pressures and the desire to limit financial risks to a minimum, professional project management using modern information tools to coordinate and control construction time schedules and to keep a check on expenditures is becoming ever more important. Increasingly, project managers are requested to have excellent communication skills and to be sensitive to environmental and social issues.

2.7.2
Inclusion of Resettlement and Environmental Mitigation

Implementation of a large dam project is not restricted only to the physical construction of the scheme itself, but equally importantly includes the successful realization of environmental and social mitigation measures. The costs of these measures are part of the normal cost of the scheme and form part of the project equity.

2.7.3
Influx of Workers

The desire to build large schemes faster and more efficiently, crucial for private sector financed projects, will often mean that cheap but well-trained skilled labor from other countries is hired by contractors.

2.7.4
Monitoring by Independent Panel of Experts

The regular inspection of ongoing construction and equipment manufacture as well as socio-environmental mitigation measures by an independent Panel of Experts (POE) is increasing to ensure that the developers, contractors and equipment manufacturers follow prescribed standards and work specifications. The POE should be able to discuss and help solve unexpected problems of whatever nature. For privately financed projects, independent experts should safeguard the interests of the government.

2.7.5
Training of Operator Personnel

Increasingly, operator and administrative personnel receive training during the construction period. This training can take place in similar schemes already in operation and/or on the premises of equipment manufacturers. Those who will be responsible for operation and maintenance of equipment should participate in the construction activities.

Training should specifically include safety and environmental monitoring activities.

For projects in developing countries it is wise to train about twice the number of people needed to counter the usually high fluctuation of staff.

2.8

TRENDS IN OPERATION

2.8.1
Project Operation and Maintenance

Lessons from the past are that only a well-trained and well-equipped project staff with sufficient authority can ensure reliable and efficient operation. In developing countries it would often be advisable to engage a number of expatriate specialists, under whose guidance the project is run and maintained during the first few years of operation, with training of local staff and progressive hand-over of duties.

Regular operational tasks can now be scheduled, monitored and administered by computer, greatly facilitating the project administration.

For reservoir storage projects in particular, it is recommended that monthly or 10-day water releases be optimized in a strategic way to maximize revenues and minimize environmental impact of the project.

Catchment management and protection should be seen as part of normal project operation and is of common interest to the project proponent and environmentalists. Likewise attention should be paid to mandatory releases to the downstream river, the trend here being away from constant releases toward a pattern which to some extent follows the 'natural' seasonal flow cycle, albeit at a reduced discharge level, for the benefit of the downstream aquatic ecology.

2.8.2 Project Operation During Abnormal Events

Personnel of large dam projects must be trained to react decisively and correctly to any emergency situation which could possibly arise.

Contingency plans must be available, the chain of command must be clear, regular drills should be organized so that the operations staff is prepared for any eventuality, and systems should be in place and tested to warn or even evacuate the downstream population.

Flood forecasting and, when appropriate, controlled releases of flood waters to minimize flood damages, should become the rule rather than the exception.

2.8.3 Outsourcing Operation and Maintenance

Many of the private developers of large dam projects are not familiar with the operation and maintenance of such schemes. To ensure the highest efficiency and to reduce outage times, they outsource project operation and maintenance to specialist companies.

2.8.4 Safety Inspections

Safety inspections by an independent Panel of Experts (POE) should regularly be carried out. This panel should have full and unlimited access to all operation data and logging devices.

2.8.5 Monitoring of Environmental and Social Impacts

The monitoring of environmental and social impact of the project is best carried out in partnership with independent organizations, funded by the proceeds of the dam project.

Every five years or so a comprehensive ex-post evaluation should be carried out to verify whether project expectations have been met and to determine where further remedial action, to be paid by the project, is required. Ex-post evaluations play an important role in understanding the real environmental and social impact of large dams.

2.9 REHABILITATION AND UPGRADING OF EXISTING DAM PROJECTS

2.9.1 Review of Safety

As existing dams grow older, it becomes increasingly important to regularly re-assess their safety aspects. This would best be done by independent experts, rather than by the owner's personnel, to avoid cover-ups of findings which might embarrass maintenance personnel or perhaps lead to expensive repairs for which the owner would be reluctant to pay.

A thorough review of the safety aspects of existing dams every ten years or so could help to avoid potentially catastrophic situations.

The review of safety aspects could lead to design changes (for example, additional spillway capacity), installation of additional instrumentation, changes in operation, additional operator training, installation of warning systems, and so forth.

The growing importance of environmental awareness, established recreational activities and new project duties may lead to changes in modes of project operation.

2.9.2 Upgrading Existing Dam Projects

It is often possible to boost the performance of existing projects, with relatively little incremental environmental or social impact, and to avoid, or delay, the construction of new dam projects.

2.10
LONG TERM TRENDS

2.10.1
Increasing Importance of Water Rights

The growing world population and the increasing needs will make water an increasingly precious commodity. The competition and conflicts about water will increase. It will become increasingly important that national and international water rights are recognized and honored.

2.10.2
Increasing Difficulty for Vulnerable People to Pay for Water

Increased use and competition of water will also lead to higher costs, and this has two main consequences.

- There will be increasing emphasis on water conservation and water re-use.
- With higher prices, it will become more difficult for the poor to pay for drinking and irrigation water. Social considerations in the planning and design of dam projects may therefore become an important issue.

2.10.3
Prospects for Pumped-Storage Plants

In the long term the role of renewable energy production, particularly solar and windpower, will increase. Some sort of energy storage will be required to offset the considerable fluctuations inherent to solar and windpower plants.

Compensation can be provided by conventional hydropower plants, provided they have a reasonable size reservoir, but also by pumped-storage schemes. The role of pumped-storage plant is therefore likely to increase in the long-term. This includes underground pumped-storage plants which would in some cases make use of disused underground mines.

Other storage devices which are getting increased attention are SMES (Super Magnetic Energy Storage), battery storage and storage of compressed air in underground caverns.

2.11
SUMMARY TABLE ON TRENDS

The following table summarises recent trends in both the electricity business and the environment.

Table 4: ***Summary of Trends in the Electricity Business and the Environment***

Electricity and Hydropower Business Trends
• Global restructuring of the electricity industry; electricity becoming a commodity rather than a public service. • Electricity price evolution towards market-driven pricing. Low prices of fossil fuels. • Issue of global warming as a business factor: CO_2 tax debate, tradable emissions credits, Kyoto Protocol. • Increased role of private investors in the electricity business. • Focus on short-term returns. • Conflict between economic optimization and financial viability: economic planning may internalize external costs, while financial analysis is focused on monetary cash flows, which exclude costs borne by society. • Decrease of Integrated Resource Planning as a strategic planning tool. • Less focus on energy security than in the '70s and '80s.

Table 4 (cont'd)

Electricity and Hydropower Business Trends (cont'd)
• Falling R&D investments by electric utilities. • Shorter planning and construction cycle for projects due to technological developments and financial constraints. • Increasing regulatory and legal requirements (e.g., new European Union regulations). • Integration of transmission systems and markets may orient hydropower towards peaking supply. • Increased power needs in tropical and subtropical areas, where the hydropower potential is the greatest, but where the environmental/social challenges are also the greatest.

Environmental/Social Trends
• Increasing concerns about irreversible losses of biodiversity. • Increasing concerns about global warming and air pollution, demands for restrictions on CO_2 emissions. • Increasing concern about poverty alleviation as an international development focus. • Increasing concerns about the loss of cultural diversity and support for ethnic minority rights. • Increasing demands for public participation. particularly in the case of indigenous people and minority groups. • Decrease in Ministries of Environment budgets. Increase in environmental self-responsibility for the electricity industry. • Electricity industry increasingly adopting Environmental Management Systems (EMS), such as International Standards Organisation (ISO) 14 000. • Increased concerns about water scarcity and water quality. • Trend towards Integrated Watershed Management, replacing a sectoral approach to water resource management (Dublin Principles: see footnote 19 page 5). • Increased demands on reservoir managers to support multiple uses of reservoirs. • Hydropower increasingly perceived as one of a number of initiatives helping to limit the increase in GHG emissions. • The sustainability of large hydropower projects is questioned by opponents of this option. • Trend towards greater consideration given to the decommissioning of dams. • Polarization of opinion between hydro proponents and opponents over the local vs. regional / global effects of hydropower. • International organizations debating the relevance of hydropower and large dams from an environmental perspective that could influence the nature of future development (e.g., World Commission on Dams). • Trend towards improving EIAs so that they become more efficient decision-making tools. • Recent emphasis on Sectoral EIA as a decision making tool. • Trend towards integrating traditional ecological knowledge into EIAs.

2.12 CONCLUSIONS

This section provides a broad overview of the lessons learned and trends in the planning, design, construction and operation of large dam projects. In conclusion, the main trends for large dam projects seem to be:

- increased understanding and awareness of complex technical, environmental and social issues which are inherent to large dam projects; and realization that the development of large dam projects involves a trade-off between the benefits gained against losses
- fully integrate EIA into the hydropower planning process
- increased public interest and scrutiny of large dam projects
- increased public consultation in identifying and screening of projects
- a holistic approach with increased application of multi-criteria ranking models and quantification of secondary and external costs and benefits to select the most attractive hydro projects and alternatives
- growing recognition that hydro is a major instrument in the fight against climate change
- increased difficulty to compete with thermal generation in countries with abundant gas supply
- increased awareness that environmental sustainability and high discount rates are in conflict
- increased private sector financing and, as a consequence, drive to cut costs and duration of design and construction, and to reduce financial risks
- a number of technological developments which make the planning and construction of large dam projects more efficient
- the recognized need for independent monitoring and control of project cost, dam safety and environmental and social impact during all phases of project design, construction and operation
- increased need for safety inspection and environmental management of existing dam projects
- increased interest in modernization and upgrading of existing schemes.

With increasing public scrutiny of environmental and social impacts, the trade-off between the overall benefits of hydropower and its overall costs will be more explicit to decision makers.

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3 COMPARATIVE ENVIRONMENTAL ANALYSIS OF POWER GENERATION OPTIONS

3.1 INTRODUCTION

This chapter presents a summary of the results of comparative studies on the environmental impacts of electricity generation systems. It is based on numerous life-cycle assessments (LCAs) carried out around the world over the last decade.

This summary focuses mainly on *biophysical* impacts which can be quantified. Social issues are not discussed in the present chapter. But since they are important for hydropower development, they are addressed in other sections of this report.

The comparison of power generation systems can be considered "generic", because it presents a general overview of environmental impacts that can be "normally" expected. Some of the discussed impacts can be greater or smaller, according to site specific conditions or mitigation measures.

These "generic" comparisons can be useful for decision-makers, for the following reasons:

- Policy decisions are often needed before site specific information is available. These "generic" comparisons will guide these decisions.
- Many political debates on energy systems do not consider the environmental impacts of entire fuel processes, including "upstream" of plants (such as extraction of fossil fuels) and "downstream" of plants (such as waste disposal). This summary will try to include issues of the entire energy system.
- In many assessments, the reliability of electricity supply is often neglected. This essential consideration will be integrated as much as possible in this chapter (this issue is not normally included in LCAs).
- At the planning level for power generation systems, the "generic" data is not a substitute for detailed analysis of site specific conditions. Nevertheless, it can provide an indication of which impact may require the most mitigation efforts.

The following section (3.2) will discuss the methodological issues related to the comparison of power generation systems. This discussion is important in order to understand the underlying assumptions and limitations associated with this type of research. Section 3.3 will then present the results for each "quantifiable" environmental impact and section 3.4 will present a summary of potential impacts with regards to qualitative issues such as biodiversity and human health.

3.2 METHODOLOGICAL ISSUES RELATED TO THE COMPARISON OF POWER GENERATION SYSTEMS

3.2.1 Potential Uses of Life-Cycle Assessment (LCA)

A life-cycle assessment is an environmental assessment of all of the steps involved in creating a product. Its goal is to avoid giving a wrong picture of products, by including any significant upstream and downstream impact. In the power sector, the assessment should include extraction, processing, transportation of fuels, building of power plants, production of electricity, waste disposal, refurbishment and decommissioning. In practice however, some steps such as decommissioning may not be studied in detail.

Life-cycle assessment can also be designed to meet different purposes. Understanding the purpose of such studies is essential to understand their results. The following table describes some of these purposes and how they affect the basic parameters of assessments.

Table 5: ***Potential Uses of LCAs***

Purpose of life-cycle assessment	Definition and scope of technology that is assessed	Period concerned	Examples of application
1. Performance assessment of an entity or activity	Existing power plants, even if outdated	Actual or past performance	Environmental performance reports of entities
2. Performance of specific projects, in an integrated resource plan	• Site of project is known • Modern commercial technologies • Consideration of the size of each project	Expected short-term performance	Entities strategic planning, which must consider the specific regional context where projects would be implemented
3. Generic assessment of the performance of energy systems	**• Modern commercial technologies** **• No consideration of size of plants**	**Expected short-term performance**	**The present report, where exceptional context is not considered and typical parameters are used.**
4. Performance assessment of future systems	Technologies in development	Expected long-term performance	Assessment of future technologies, based on expected development of technology

In this report, the results presented apply mainly to purpose no. 3 and occasionally to purpose no. 4 (for fuel cells). For commercial technologies, decision-makers should have relative confidence in LCA, but should be very careful in checking if data concern similar contexts (e.g., same type of coal with same level of combustion technology).

For future technologies, uncertainties are greater (for example, for fuel cells, it is difficult to define the energy chain and probable efficiency in producing hydrogen). Despite this, LCA is an essential practice for new technologies, because LCAs have constantly shown that new technologies will produce less environmental benefits than originally expected (e.g., the reduction in emissions from the use of ethanol in gasoline is partly offset by emissions in the production of ethanol).

The Case of Hydropower

Results for hydropower should be used with care because hydropower is highly site-specific. Since it is impossible to predefine one "best commercial technology" for hydropower, results of studies are largely based on the average characteristics of current installed capacity (and not of future projects which may not be known in sufficient detail). Moreover, the assessment of hydropower may differ widely depending if projects are multi-purpose projects or not. A purpose such as irrigation requires larger reservoirs, negatively affects a large number of environmental resources and leads to water losses, which reduce potential power generation. To make a fair comparison of electricity generation systems, the assessment of hydropower should only include projects without irrigation, or else parameters should be corrected to attribute impacts to each purpose. In reality though, this is not done, and for hydropower, most studies ignore the other purposes of such facilities, therefore overestimating the environmental impacts.

3.2.2
Main Atmospheric Issues Covered by Life-Cycle Assessments

The following table is a reminder of the main atmospheric issues that can be targeted by life-cycle assessments. It is important to note that many LCAs produce an inventory of emissions (e.g., SO_2) for each energy system, without trying to give an actual description of the final environmental impacts of these emissions (e.g., the impact of acid precipitation). This is due to the fact that final environmental impacts can be extremely variable, depending upon geography and other sources of pollution.

Table 6: ***Summary of Atmospheric Issues and Pollutants Involved***

Issue	Type of impacts	Precursor pollutants	Main sources
Acid rain Formation of sulfuric and nitric acid	Regional impacts on lakes, forests and materials	**SO_2:** sulfur dioxide	Smelters; combustion of coal, oil and diesel fuel; extraction of gas
		NO_x: nitrogen oxides	Mainly transportation, any combustion
Photochemical smog Formation of ozone and other toxic pollutants in the lower atmosphere	Affects human health at local and regional level. Reduces productivity of agriculture	**NO_x:** nitrogen oxides	Mainly transportation, any combustion
		VOCs Volatile organic compounds	Transportation, refineries, oil, wood heating
Particulate matter Very small particles have a direct effect on lungs	Significant effects on human health, particularly on asthmatics	**PM10** matter with diameter of less than 10 microns	Diesel, wood and coal combustion
Greenhouse gases	Climate change affecting agricultural and forest productivity and increasing the likelihood of extreme events such as hurricanes, floods and droughts	**CO_2:** carbon dioxide	All fossil fuels and the destruction of forests
		CH_4: methane	Livestock, paddy fields, landfill sites, extraction of natural gas, oil and coal, transportation and distribution of natural gas

3.2.3
Reliability of Generation Systems, a Criteria for Rigorous Comparisons

The comparative analysis of power generation systems could be made per unit of capacity (e.g., comparing systems that produce 1000 MW). However, some power plants are used at full capacity for most of the year, while others are not available for such a high use factor. Therefore, comparisons of systems based upon installed capacity would often be inappropriate. The amount of energy produced (kWh) is a much better base for comparisons. It is adopted for most LCAs. However, the reader must remember that even comparisons per kWh do not take into consideration two major issues:

- the other purposes of hydropower reservoirs, such as irrigation and flood control
- the reliability of electricity supply, which is a complex issue.

Since electricity is very difficult or expensive to store in large quantities, the reliability of electricity supply must be achieved by supplying electricity exactly at the same time as it is consumed. If this balance is not maintained, frequency fluctuations will result, with major impacts on electrical equipment (such as computers or appliances). The following table presents some "ancillary" services required to provide reliable electricity. Generation options are not all equally capable of providing such services.

Table 7: ***Ancillary Services Related to Electricity Supply Options***

Service	Description
Reactive supply and voltage control	The injection or absorption of reactive power from generators to maintain transmission-system voltages within required ranges
Regulation	The use of generation equipped with governors and automatic-generation control to maintain minute-to-minute generation/load balance within the control area to meet NERC control-performance standards
Operating reserve – spinning	The provision of generating that is synchronized to the grid and is unloaded, that can respond immediately to correct for generation/load imbalances caused by generation and transmission outages and that is fully available within 10 minutes
Operating reserve – supplemental	The provision of generating capacity and curtailable load used to correct for generation/load imbalances caused by generation and transmission outages and that is fully available within 10 minutes
Energy imbalance	The use of generation to correct for hourly mismatches between actual and scheduled transactions between suppliers and their customers
Load following	The use of generation to meet the hour-to-hour and daily variations in system load
Backup supply	Generating capacity that can be made fully available within one hour; used to back up operating reserves and for commercial purposes
System black-start capability	The ability of a generating unit to go from a shutdown condition to an operating condition without assistance from the electrical grid and to then energize the grid to help other units start after a blackout occurs

Source: Eric Hirst Consulting, Internet site.

Reliable electricity networks cannot depend only on "must-run" systems such as nuclear energy or on intermittent systems such as windpower.

In comparison, hydropower with reservoirs has a high "level of service" because it can provide all the "ancillary" services required to maintain this balance. Oil or diesel fired plants can also provide much flexibility, notably because large quantities of fuel can be easily stored.

But LCAs rarely consider the ancillary services provided by hydropower or oil. This would be difficult, because it is impossible to assign a "quality" to each kWh. However, comparisons should consider the fact that some forms of generation are intermittent (e.g., wind) and constantly require a "backup" system to compensate for fluctuations.

For intermittent production systems, two approaches can be used to compare systems fairly.

- They can be analyzed in combination with a typical backup system, providing the same reliability as other "stand-alone" systems (assessment includes the impacts of the backup).
- If the assessment does not consider the required backup, it should be recognized clearly that the assessment is not at the same level as other "stand-alone" systems.

The assessment of a combination of systems in Integrated Resource Planning is a technical challenge, but it can be done.

3.2.4 Main Types of Electricity Generation Systems Considered

Considering that the levels of service of electricity generation systems vary greatly, we will regroup systems based on their ability to meet demand fluctuations. The following table presents the main systems considered, with their characteristics.

Table 8: ***Main Generation Systems Considered, with their Expected Level of Service***

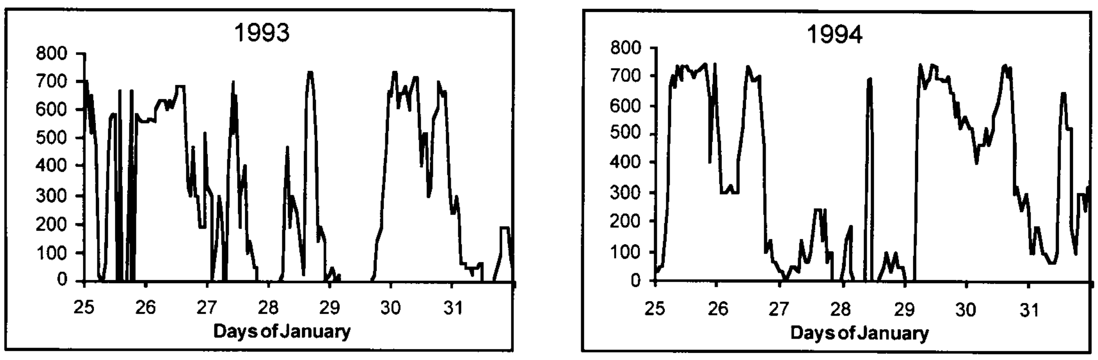
Electricity Generation Systems	Comments on reliability and flexibility of electricity production
Systems capable of meeting base load and peak load	
Hydropower with reservoir	High reliability and flexibility. Many run-of-river plants can rely on upstream reservoir, and therefore can be considered as having reservoirs.
Diesel	High reliability and flexibility.
Base load systems with less flexibility	
Natural gas combined cycle turbines	Mostly base load with technical flexibility, but constant high use factors are needed to buy gas at low price, which reduces flexibility.
Coal	Mostly base load with some flexibility.
Heavy oil	Mostly base load with some flexibility.
Hydropower run-of-river	Mostly base load with low flexibility.
Biomass	Mostly base load with low flexibility.
Nuclear	Base load only, almost no flexibility.
Systems designed to meet peak load	
Increased capacity on existing hydropower	Designed to add capacity, without adding energy.
Pumped-storage hydropower	Designed to add capacity, while reducing total energy.
Light Oil: single cycle turbines	Adds capacity and energy. Generally low use factor.
Intermittent systems that need a backup production, (no flexibility)	
Windpower	Needs a backup system with immediate response, generally hydropower with reservoir.
Solar photovoltaic	Needs a backup system with immediate response, such as hydropower with reservoir or diesel.

Since LCA focuses on energy produced, this means that systems designed mainly or exclusively to add capacity cannot be included fairly. For example, a project designed to increase the capacity of a hydropower plant may not increase the energy produced and would therefore have an infinite level of environmental impact per kWh (impacts would be divided by zero kWh). These systems will therefore not be included in this report.

3.2.5
Evaluation of Windpower Electric Service and its Impacts on Backup Options

A common misconception is that on a windy site, the wind blows and blows without stopping. In fact, even on a site with a high windpower potential, the wind blows and stops frequently on a short time basis, as shown in the figure below.

Figure 7: ***Short-term Variations in Wind Production***



(Analysis with hourly wind speed data on an excellent class 5 wind site, in Québec, Canada.)

Yearly windpower fluctuations can also be important. In the case of Québec, windpower simulations were run, with 8 years of wind data for two excellent sites (Hydro Review, Vol. XVII, No. 4, August 1998 and article submitted to Energy Policy). In the best year, for 37% of the time, wind production would have been less than 20% of installed capacity. In the worst year, for 60% of the time, production would have been less than 20% of capacity. These simulations show that both short-term and long term fluctuations should be expected.

However, it is generally assumed that large electricity networks have other sources of generation to compensate for such windpower fluctuations. In most cases, this assumption is valid, but adding wind farms to a network has impacts on other generation. So windpower must be evaluated in combination with its backup production option(s).

Wind fluctuations happen quickly and backup options must be able to increase their generation almost instantly. As a consequence, the most likely backup are oil or coal fired, or often hydropower which is very flexible.

If Backup is Provided by Fossil Fuels

If windpower is backed up by oil or coal plants, these plants cannot be used to produce at close to their maximum capacity and must have "spinning reserve" to be able to increase generation rapidly. In some cases, this means that oil or coal plants may have to operate at lower efficiency than otherwise, in order to be ready to compensate for wind generation instability. Therefore, on a per kWh basis, the thermal plants may be slightly more polluting because of windpower. This issue should be part of the assessment of windpower.

Nevertheless, in a network dominated by fossil fuel generation, windpower development is still environmentally justified because it can seriously reduce emissions. However, this benefit can be slightly less than normally expected.

If Backup is Provided by Hydropower

When windpower is developed, backup capacity must be available or be built, which applies to hydropower or to any other backup. With respect to environmental issues, a hydro backup is different from a thermal backup, because hydropower plants can reduce and increase generation with minimal efficiency losses and no emissions.

The development of windpower can have indirect environmental impacts by affecting river flows. In the Québec context, simulations indicate that the main concern is related to periods when river flows are at their lowest, in summer, when hydropower demand is also low at around 10000 MW (from a network with maximum capacity of 35000 MW).

If 3000 MW of windpower are installed, on each summer windy day, the flow of these rivers would have to be reduced seriously (or if minimum river flows are legally required, unproductive water spillage would be required).

Conclusion

Windpower has indirect economic costs. Because it has only intermittent energy to offer and no reliable capacity, either ancillary services have to be bought or additional backup capacity is required. The fact that extra capacity is already built and available does not eliminate the backup costs, because in open markets, this existing available capacity can be used to sell electricity at a higher price during peak hours.

It is important to note that some impacts of windpower on electricity networks are proportional to the installed capacity, relative to the size of the network (10 MW of wind in a 500 MW network having similar effect as 100 MW of wind in a 5000 MW network). For projects that are relatively small, the impacts are small in absolute terms but they are not eliminated. The impacts are only more difficult to perceive, but they still exist.

Depending of circumstances, the assessment of windpower should include the following issues.

- If ancillary services are bought to compensate for windpower fluctuations, part of the life-cycle environmental impacts of backup options should be included.

- If the backup option is fossil fueled, the effect on emissions should be accounted for. Because of wind fluctuations, it might not be possible to run the fossil fueled plant within the best conditions (efficiency losses, frequent shut downs and start-ups).

- If the backup option is hydropower, the effects on river flows should be investigated.

Environmental impacts of the required backup must be included in a complete assessment of windpower. This does not mean that windpower development is not justified from an environmental point of view. Even including the impacts of backup options, there are many instances where windpower could seriously reduce air emissions, notably by reducing the use of oil and coal.

3.3 RESULTS OF LIFE-CYCLE ASSESSMENTS

This sections presents the results of LCAs for most quantifiable parameters covering issues such as atmospheric emissions, land requirements and occupational health. For each parameter, we present a range of results from studies carried out in different countries.

3.3.1 Life-Cycle "Energy Payback Ratio"

Environmental Issues

For each power generation system, the "energy payback ratio" is the ratio of energy produced during its normal life span, divided by the energy required to build, maintain and fuel the generation equipment. It is an indirect indicator of environmental impact. If a system has a low payback ratio, it means that much energy is required to maintain it and it is likely to have more environmental impacts than a system with a high payback ratio.

Understanding the Results of Studies

In the recent context of climate change commitments, life-cycle assessments have focused mainly on greenhouse gas emissions of energy systems. These assessments are essential. However, the emissions can vary dramatically according to their context. For example, if a system utilizes aluminum as a building material, the assessment will vary greatly if the aluminum smelters use hydropower or electricity from coal.

Because the "energy payback ratio" is less affected by upstream choices of energy supply, it has the advantage of minimizing these fluctuations. It should therefore be considered as one of the most reliable indicator of environmental performance.

If this indicator minimizes some fluctuations in study results, it does not eliminate them. The data in the following table shows that payback ratios do not vary much for fossil fuels, but vary significantly for renewable energies. This is due to variable site conditions (topography for hydro, quality of the wind, intensity of solar radiation for solar energy).

Table 9: ***Life-Cycle Energy Payback Ratio (1/2)***

		World	Europe			Asia
Electricity Generation Options (classified by level of service)	**Range of Life-Cycle Values**	**IEA, "Benign Energy?" 1998**	**Finland, Lappeenranta U. of Tech., Kivisto, 1995**	**Denmark, DWTMA, 1997**	**Austria, Graz U. of Tech., Lehrhofer,[4] 1995**	**Japan, CRIEPI, Uchiyama, 1996**
Options capable of meeting base load and peak load						
Hydropower with reservoir	48 to 260				56 to 260 20 to 1 600 MW UF 42 to 64% life 50 y	50 [5] 10 MW UF 45%
Diesel						
Base load options with limited flexibility						
Hydropower run-of-river	30 to 267				30 to 60 20 to 50 MW UF 68% life 50 y	50 [5] 10 MW UF 45%
Bituminous coal: modern plant	7 to 20		11 [2]	9		7/17 to 20 [6,7]
Brown coal: old plant						
Heavy oil without scrubbing	21					21
Nuclear	5 to 107		7 to 12		17	24 to 107 [6]
Natural gas combined cycle turbines	14		14[3]			
Large fuel cell (nat. gas to hydrogen conversion)						
Biomass: Energy plantation	3 to 5					
Biomass: Forestry waste combustion	27					
Intermittent options that need a backup production (such as hydro with reservoir or oil-fired turbines)						
Windpower	5 to 39		35 UF 22%	26 to 34 600 kW UF 21 to 26% life 20 y	7 to 33 0,01 to 3 MW UF 8 to 51% life 20 y	6 100 kW UF 20%
Solar photovoltaic	1 to 14	2 to 14 [1]	2 30 kW UF 10%		1 to 4 300 kW UF 11% life 20 y	5 1 MW UF 15%

Acronyms :

UF: use factor
EPR: energy payback ratio
O & M: operation and maintenance

1 Calculated from cited data. Do not include all the life cycle, only the production of a photovoltaic module.
2 Coal imported from Russia & Poland. (Values calculated from data.)
3 Natural gas imported to Finland from Russia.(Values calculated from data.)
4 Wide range of values for hydro is explained by the project sizes (20 & 1 600 MW) and for wind by the average wind speeds (5,5 & 7 m/s).
5 No distinction between run-of-river and reservoir.
6 Imported resources.
7 1st value for CO_2 removal, 2nd & 3rd for conventional and advanced technologies.

Table 9: ***Life-Cycle Energy Payback Ratio (2/2)***

	North America					
Electricity Generation Options (classified by level of service)	**USA, Cornell U., Pimentel et al., 1994**	**USA, FTI, U. of Wisconsin-Madison, White & Kulcinski,[11] 1999**	**Canada, Enviro-science inc., Bélanger,[12] 1995**	**Canada, Hydro-Québec, Peisajovich, 1997**	**Canada, U. of Guelf, Gingerich and Hendrickson,[15] 1993**	**Comments**
Options capable of meeting base load and peak load						
Hydropower with reservoir	48 [8] includes reservoirs designed for other uses			205 [13]		Refurbishment instead of dismantling can almost double the ratios. Values highly dependent on site characteristics.
Diesel						
Base load options with limited flexibility						
Hydropower run-of-river				267 [14]		Refurbishment instead of dismantling can almost double the ratios. Values highly dependent on site characteristics.
Bituminous coal: modern plant	8	11				
Brown coal: old plant						
Heavy oil without scrubbing						
Nuclear	5	16				
Natural gas combined cycle turbines						
Large fuel cell (nat. gas to hydrogen conversion)						
Biomass: Energy plantation	3 [9]		5			Values highly dependent on wood quality and on transportation distance. Use of wood wastes produced at in a short distance from plant gives a high EPR compared to large energy plantations.
Biomass: Forestry waste combustion					27	
Intermittent options that need a backup production (such as hydro with reservoir or oil-fired turbines)						
Windpower	5 [10] UF 35%	17 to 39 343 to 750 kW UF 24 to 35 life 20 to 30 y				Values highly dependent on turbine capacity, life, and site use factor. The main energy requirement is related to material production, followed by O & M (White & Kulcinski 1999). Values do not consider the energy investments required for backup production.
Solar photovoltaic	9 UF 21% life 20 y					Values highly dependent on sun exposure. Values do not consider the energy investments required for backup production options.

8 Includes reservoirs for other uses (flood control, drinking water, storage, irrigation).
9 Energy plantation.
10 1994 or earlier turbines on a favorable site. Do not include O & M.
11 Wind project sizes ranging from 2 turbines (1,2 MW total; EPR 17) to 143 turbines (107 MW total; EPR 39).
12 Energy plantation. Value calculated for a transportation distance of 40 km.
13 Mean of 3 large projects in Quebec.
14 Beauharnois (Quebec) power plant.
15 Whole tree chipping (poor quality, mainly pole-sized spruce). Includes engine and hydraulic oil. Main energy input is related to transportation of the chips to the burning facilities (240 km round trip).

Main Findings Concerning "Energy Payback Ratios"

Reservoir based hydropower clearly has the highest performance: its energy payback ratio varies between 48 and 260, while those of systems based on fossil fuels are in a range of 7 to 21. The advantage of hydropower is in fact greater than this when we consider two other aspects.

- The lowest factors for hydropower include projects that were designed for irrigation. Even with this multiple use, hydropower still performs better than any other system.
- Some of the calculations were made with a life-span of 50 years for hydropower. Some experts consider that a life span of 100 years should be used for hydropower, with one replacement of turbines. In this case the payback ratios would be almost doubled.

In the table, windpower, for the best wind sites, also has a high energy payback ratio. However, this ratio is overestimated because the calculations did not consider the need for backup capacity to compensate wind fluctuations. As shown previously (in section 3.2.3), the level of service of windpower is very low, even when many wind sites are spread out over a large territory.

For biomass, the energy payback ratio varies between 3 and 27. This variation is explained by differing contexts: biomass plantations created exclusively for electricity generation (low factors, because they require many energy input) or else the use of waste biomass in an industry such as pulp and paper (high factors).

In the case of fossil fuels, energy payback ratios are and will be declining over the next decades. This is due to multiple factors.

- As the best fossil reserves are depleted, they tend to be replaced by wells that require a higher rate of energy investment (located in far away regions or under the sea).
- Environmental considerations may involve selecting resources that are located at greater distances. For example, transportation of coal by train in the US has increased in the last decade because users tend to select Western low sulfur coal.
- In the future, there will be more energy spent or wasted in fossil-fired power plants, in order to reduce emissions. Scrubbing of sulfur reduces the efficiency of a plant. If capture and sequestration of CO_2 becomes commercially available, this will involve spending huge amounts of energy in the operation of scrubbing and disposal equipment.

3.3.2 Contribution to Climate Change: Life-Cycle Greenhouse Gas (GHG) Emissions

Environmental Issues

The Intergovernmental Panel on Climate Change makes the following comments on the environmental impacts of climate change (IPCC, 1996, p. 6-7).

- "Warmer temperatures will lead to a more vigorous hydrological cycle; this translates into prospects for more severe droughts and/or floods in some places...
- Sustained rapid climate change could shift the competitive balance among species and even lead to forest dieback..."
- "Models project an increase in sea level of about 50 cm from the present to 2100."
- "Future unexpected, large and rapid climate system changes... are by their nature, difficult to predict. This implies, that future climate changes may also involve 'surprises'."

Understanding the Results of Studies

Because of these potential impacts, many studies have focused on assessing GHG emissions of energy systems. These studies produce data on emissions of CO_2 equivalent. This means that CO_2 and other greenhouse gases have been included in the assessment. But other greenhouse gases have different effects on the climate and may have a different atmospheric life. To take into account these differences, the IPCC has produced a set of "global warming potential" indicators, relative to CO_2. In LCAs, each greenhouse gas is converted to an equivalent of CO_2 and added to the inventory (see following table).

Table 10: ***Major Greenhouse Gases Affecting Assessment of Energy Systems***

Species	Chemical formula	Global warming potential per kg over 100 years (IPCC,1996)
Carbon dioxide	CO_2	1
Methane	CH_4	21
Nitrous oxide	N_2O	310
Perfluoromethane	CF_4	6 500
Perfluoroethane	C_2F_6	9 500

CO_2 and CH_4 are directly related to energy systems and included in most studies. Any combustion will produce CO_2 and commercial natural gas is composed of 95% CH_4. Other greenhouse gases may not be included, because of the low volumes involved in energy systems. However, considering their global warming potential, they could affect significantly the results.

In the next table on GHG emissions, results vary according to whether studies considered best available commercial technology or average technology. For fossil fuels, no commercial scrubbing of CO_2 is currently available and variations in emissions depend mainly on the efficiency of plants.

Table 11: ***Life-Cycle Greenhouse Gas Emissions (kt eq. CO_2/TWh) (1/2)***

		World		Europe					Asia
Electricity Generation Options (classified by level of service)	**Range of Life-Cycle Values**	**IEA, "Benign Energy?" 1998**	**a: ETSU, UK and IER and b: EEE, UK and Enco, 1995**	**Switzerland, PSI, Dones et al., 1996**	**Finland, Lappeen-ranta U. of Tech., Kivisto, 1995**	**UK, ETSU, Bates,[11] 1995**	**Austria, IAEA, Vladu, 1995**	**Germany, ÖKO-Inst., Fritsche, 1992**	**Japan, CRIEPI, Uchiyama, 1996**
Options capable of meeting base load and peak load									
Hydropower with reservoir	2 to 48	4 to 15[1]						2[12]	18[13]
Diesel	555 to 883		624/883[6]a	555[9]		778			
Base load options with limited flexibility									
Hydropower run-of-river	1 to 18	9[2]						2[12]	18[13]
Bituminous coal: modern plant	790 to 1 182		823 to 1074[7]a	1 081[8]	894	1 082	790	1 021	859 to 991[14]
Lignite: old plant	1147 to 1272+		1 147 a					1 162	
Heavy oil without scrubbing	686 to 726+								686
Nuclear	2 to 59			12[8]	10 to 26	4	35	59	2 to 21[14]
Natural gas combined cycle turbines	389 to 511		407 a	390[9]	472	453	480	456	
Large fuel cell (nat. gas to hydrogen conversion)	290+ to 520+								
Biomass: Energy plantation	17 to 118	17 to 27[3]							
Biomass: Forestry waste combustion	15 to 101	29[4]							
Intermittent options that need a backup production (such as hydro with reservoir or oil-fired turbines)									
Windpower	7 to 124	7 to 9	9 b		14			11	124[15]
Solar photovoltaic	13 to 731	107 to 211[5]		731[10]	95			30	126

Acronyms :

UF: use factor

UCPTE: *Union pour la coordination de la production et du transport de l'électricité*

GHG: greenhouse gas

1 Large scale hydro. Estimated emissions from construction and reservoir.
2 Small hydro (< 10 MW), not necessarily run-of-river.
3 1st value for the forestry residue fuel cycle, transportation of 100 km round-trip, 2nd and 3rd value for energy crops cycle in different countries.
4 Excluding emissions at plant.
5 Range of data includes different cell types, roof mounted.
6 1st value for combine cycle base load plant, 2nd for gas turbine peak load plant.
7 1st value for integrated gas combined cycle, 2nd for atmospheric fluidized bed combustion.
8 Values for Austria in 1990.
9 Projected values for UCPTE countries in 20005-2015.
10 3 kW.
11 Transmission and distribution included.
12 No emission accounted from reservoir.
13 No distinction is made between run-of-river and reservoir type of hydropower.
14 Advanced and conventional technology.
15 100 kW turbines with a UF of 20%.

Table 11: ***Life-Cycle Greenhouse Gas Emissions (kt eq. CO_2/TWh) (2/2)***

	North America							
Electricity Generation Options (classified by level of service)	**USA, FTI, U. of Wisconsin, White & Kucinski,[16] 1999**	**USDOE, Argonne National Laboratory,[17] 1992**	**USA, NDCEE,[18] 1997**	**Canada, Hydro-Québec, a: Gagnon 1999 & b: Bélanger, 1998**	**Canada, FFCC, 1995**	**Canada, SECDA, 1994**	**USEPA, AP-42, 1998 & 1999**	**Comments**
Options capable of meeting base load and peak load								
Hydropower with reservoir				10 to 30 a		48 [19]		Refurbishment instead of dismantling can almost reduce emissions by 50%. Values highly dependent on site characteristics.
Diesel							704 [23] (plant only)	
Base load options with limited flexibility								
Hydropower run-of-river						1		Refurbishment instead of dismantling can almost reduce emissions by 50%. Values highly dependent on site characteristics.
Bituminous coal: modern plant	974			913 b	910	1 182	1 029 [24] (plant only)	
Lignite: old plant							1 272 [25] (plant only)	
Heavy oil without scrubbing							726 [23] (plant only)	
Nuclear	15					2		
Natural gas combined cycle turbines				511 b	433	389	407 [26] (plant only)	
Large fuel cell (nat. gas to hydrogen conversion)		290 to 520 (plant only)	378 (plant only)			353		
Biomass: Energy plantation Biomass: Forestry waste combustion						118 [20] 15 / 101 [21]		Values highly dependent on wood quality and on conditions of exploitation (transportation distance, etc.).
Intermittent options that need a backup production (such as hydro with reservoir or oil-fired turbines)								
Windpower	9 to 20					11 / 38 [22]		Values highly dependent on turbine capacity, life, and site use factor. Values do not consider emissions from required backup production.
Solar photovoltaic						13		Values highly dependent on sun exposure. Values do not consider the emissions from required backup production.

16 CO_2 emissions only. Wind project sizes ranging from 2 turbines (1,2 MW; high emissions) to 143 turbines (107 MW; low emissions).
17 200 kW, thermal efficiency 40 – 60%, life 5 y.
18 200 kW, thermal efficiency >40%, 85% if heat is recovered.
19 GHG emissions from reservoir included from preliminary research. (Data is site specific, not averaged.)
20 Poplar plantation (Data is site specific, not averaged.)
21 1st value for soft wood waste, 2nd for loggin residue, both excluding emissions at plant. (Data is site specific, not averaged.)
22 Class 7 & 6 wind sites. (Data is site specific, not averaged.)
23 Thermal efficiency 35%.
24 Medium-volatile bituminous, thermal efficiency 35%.
25 Thermal efficiency 35%.
26 Thermal efficiency 45%.

Main Findings Concerning Greenhouse Gas Emissions

In the preceding table, run-of-river hydropower has the highest performance among all systems, followed closely by another group with similar emission factors: nuclear, reservoir based hydropower and windpower.

However, the issue of level of service is not included in this ranking. Run-of-river hydropower (without an upstream reservoir) as well as nuclear energy both have low electricity generation flexibility, while windpower is intermittent. These three energy systems all require a backup system which may be based on fossil fuels, thereby increasing significantly the final emissions factor of these options.

Coal (modern or old plant) has clearly the worst emission factor, with twice the emissions of natural gas combined cycle turbines.

The emission factors of hydropower, with reservoir or run-of-river, would be much lower if we use a life-span of 100 years (many studies use 50 years).

The assessment of hydropower with reservoirs can be site-specific, depending upon two factors: first, the amount of flooded biomass per hectare can vary by a factor of 5 (500 t/ha for tropical forest versus 100 t/ha for boreal climate) and affect emissions from reservoirs; second, the area of reservoir per kWh can vary according to topography. For projects with an average size of reservoir per kWh, in boreal or mountain regions, hydropower has an emissions factor approximately 20 to 60 times lower than coal-fired generation.

Scientific uncertainties are relatively low for most of these results. Nevertheless, uncertainties persist for biomass and hydropower.

- The system with the highest level of uncertainty is biomass. This depends upon one key issue that needs to be resolved. If a forest or plantation is used to produce energy, does it store carbon permanently in soils?
- For GHG emissions from decaying biomass in hydropower reservoirs, uncertainties still persist. For reservoirs in boreal or mountain regions, the amount of flooded biomass is small and because of this, it is unlikely that future research will arrive at higher emission factors than those reported in the table on GHG emissions. For reservoirs in tropical environments, emission factors could be higher, but would depend on many site-specific conditions. Many studies do not consider emissions from reservoirs in the assessment of hydropower.

3.3.3 Land Requirements

All electricity generation systems use large areas of land. These land "requirements" can be considered as an indirect indicator of some environmental impacts. Examples of these various types of impacts include:

- for hydropower, the transformation of forests/land into aquatic ecosystems
- for coal, the use of large areas for mining activities
- for biomass, the area of forests that is exploited.

Understanding the Results of Studies

This type of assessment must be considered with prudence, because it does not consider the intensity of the impact. Moreover, the data in the following table considers only the direct use of land. It does not consider indirect impacts, such as losses related to climate change (ex. losses due to increase in sea levels).

The results for hydropower vary significantly because of site-specific conditions. The figures are for projects designed mainly for power generation. In some countries, such as the United States, most reservoirs were created for purposes of irrigation and water supply. Many of these reservoirs involve very little or no power generation and would have even higher land use factors, per TWh.

For fossil fuels, very little data exists and some upstream activities are not considered. For example, surface mining of coal would require much more land than underground mining, but the data does not allow for such distinctions.

Main Findings Concerning Land Requirements

Nuclear energy clearly has the lowest land requirements, if we do not consider the land required for long-term waste disposal. The inclusion of this use of land would seriously increase the land requirements, because a small area of land is needed, but for many thousands of years (if 0,1 km^2/TWh/y is required for waste disposal, multiplied by 30000 years, applied to 30 years of generation, the factor would increase from 0,5 km^2/TWh/y to 100 km^2/TWh/y).

Despite the low diversity of available data concerning fossil fuel systems, the data show that they require much less land than any renewable source of energy. This is an assessment based on direct land requirements only. Indirect "use" of land, related to fallout of atmospheric emissions or related to the impacts of climate change, are not included in the data. These areas are huge and could multiply the land "use" factors of fossil fuels.

Biomass plantations is the system that requires the most land per unit of energy.

Other renewable sources (hydropower, windpower and solar power) have similar land requirements, which can vary significantly according to site-specific conditions. Data on hydropower is based on area of reservoirs, and not on flooded areas which would be necessarily smaller.

Table 12: ***Land Requirements* (km²/TWh/y)***

		World		North America				
Electricity Generation Options (classified by level of service)	**Range of Life-Cycle Values**	**World Energy Council, 1999**	**Canada & Austria, Hydro-Québec & IAEA, Gagnon & van de Vate, 1997**	**USA, Cornell U., Pimentel et al., 1994**	**USA, Gipe, 1997**	**Canada, Enviro-science inc., Bélanger,[6] 1995**	**Canada, SECDA, 1994**	**Comments**
Options capable of meeting base load and peak load								
Hydropower with reservoir	2 to 152 projects designed production for energy		Québec: 152 Finland: 63 Switzerland: 2 China: 24 Sweden: 25 Africa: 639 Asia: 41 Lat. Am.: 105	750 [3]			110	Values represent total reservoir area, not flooded area. Values highly dependent on site charasteristics. Multi-purpose reservoirs increase land requirements.
Diesel								
Base load options with limited flexibility								
Hydropower run-of-river	0,1						0,1	
Bituminous coal: modern plant	4			4				
Lignite: old plant								
Heavy oil without scrubbing								
Nuclear	0,5			0,5 [4]				
Natural gas combined cycle turbines								
Large fuel cell (nat. gas to hydrogen conversion)								
Biomass: Energy plantation	533 to 2200			2 200		533		Values highly dependent on wood quality and conditions of exploitation (transportation distance, etc.).
Biomass: Forestry waste combustion	0,9+						0,9 [7] (plant & waste storage only)	
Intermittent options that need a backup production (such as hydro with reservoir or oil-fired turbines)								
Windpower	24 to 117	48 [1]	72 [2]	117 [5]	24 to 71		65 / 29 [8]	Values highly dependent on turbine capacity, life, and site use factor. Values do not consider land requirements for backup production.
Solar photovoltaic	27 to 45			27			45	Values highly dependent on sun exposure. Values do not consider land requirements for backup production.

Acronyms :

UF: use factor

Lat. Am.: Latin America

* Data for each year of production, life-span have no effect on factors.

1 10 MW/km², with a UF of 25% and 95% availability.
2 Matane (Canada) project, includes a reserved edge zone.
3 Includes reservoirs for other uses (flood control, drinking water, storage, irrigation).
4 Does not consider long-term storage of nuclear wastes.
5 1994 or earlier turbines, assuming a 35% UF.
6 Energy plantation (15 dry t/ha/y).
7 Crop or logging residues and softwood waste. (Data is site specific, not averaged.)
8 Data for 30 MW / 75 MW. (Data is site specific, not averaged.)

3.3.4 Contributions to Acid Precipitation: Life-Cycle Sulfur Dioxide (SO_2) and Nitrogen Oxide (NO_x) Emissions

Environmental Issues

The following two tables present the results of studies concerning the two major precursors of acid precipitation:

- the main precursor is SO_2, which leads to the formation of sulfuric acid
- the other precursor is NO_x, which leads to the formation of nitric acid (before contributing to the formation of acid precipitation, NO_x can also be involved in other chemical reactions, causing smog – This issue is discussed in the next section).

Acid precipitation is still a major issue in many parts of the world. Even in North America where programs have reduced emissions, specialists consider that current level of SO_2 and NO_x emissions still affect the productivity of many lakes, rivers and forests. Nevertheless, it is difficult to establish a direct link between atmospheric emissions and ecosystem impacts.

In the case of forest productivity, impacts of pollutants are numerous and sometimes indirect (Godish, p. 108-12):

- acid will tend to remove some essential nutrients from soils (K, Ca, Mg)
- acid may mobilize toxic metals such as aluminum, which can damage roots
- adding nitrogen, the main nutrient of plants, may create an unbalance in resources and make trees more vulnerable to diseases and frost.

Impacts of other atmospheric pollution must be also considered:

- photochemical smog (next section) can damage the leaves
- climate change may increase heat stress or intensity of droughts.

Finally, the vulnerability of forests vary significantly according to the types of soils involved. In sum, it is impossible to establish a direct link between one type of emission and the ultimate environmental damage caused by such an emission. The emission factors presented in the following tables must therefore be considered as indicators of "potential" impacts.

Understanding the Results of Studies on SO_2

When looking at the next table on SO_2 emissions, the reader should keep in mind that SO_2 emissions may vary significantly, according to the following factors for each fossil fuel.

- For coal, the sulfur content can vary from 0,5% to 5% and even more in exceptional cases.
- For oil, average sulfur content in light oil/diesel is about 0,2% and 2% for heavy oil, but these percentages can vary significantly from one region to another.
- Commercial natural gas has virtually no sulfur, because it is removed in processing plants after extraction. Depending upon sulfur concentrations and regulations, this process can create high or low SO_2 emissions.
- There is a wide variety of technologies to reduce emissions at plant, with different performances. Some commercial scrubbing technologies that are currently available are capable of removing about 90% of SO_2 emissions. But these technologies have been implemented only in a few countries such as Japan.

Table 13: ***Life-Cycle SO_2 Emissions* (t SO_2/TWh) (1/2)***

		World		Europe				North America
Electricity Generation Options (classified by level of service)	**Range of Life-Cycle Values**	**IEA, "Benign Energy?" 1998**	**ETSU, UK, IER and Enco, 1995**	**Switzerland, PSI, Dones et al., 1996**	**UK, ETSU, Bates,[9] 1995**	**Austria, IAEA, Vladu, 1995**	**Germany, ÖKO-Inst., Fritsche, 1992**	**Canada, Hydro-Québec, Gagnon, 1999a**
Options capable of meeting base load and peak load								
Hydropower with reservoir	5 to 60	9 to 60 [1]						5
Diesel	84 to 1 550				1 550			
Base load options with limited flexibility								
Hydropower run-of-river	1 to 25	25 [2]						
Bituminous coal: modern plant	700 to 32 321+		1 100/200 [6]	1 510 [7]	1 490		700	
Lignite old plant	600 to 31 941+		668				600	
Heavy oil without scrubbing	8 013 to 9 595+							
Nuclear	3 to 50				50			
Natural gas combined cycle turbines	4 to 15 000+			155 [8]		300		
Large fuel cell (nat. gas to hydrogen conversion)	6							
Biomass: Energy plantation	26 to 160	90 to 160 [3]						
Biomass: Forestry waste combustion	12 to 140	140 [4]						
Intermittent options that need a backup production (such as hydro with reservoir or oil-fired turbines)								
Windpower	21 to 87	15 to 87	87					
Solar photovoltaic	24 to 490	220 to 490 [5]		230				

Acronyms :

FGD : flue-gas desulfurization
SCR : selective catalytic reduction
UF: use factor
UCPTE: *Union pour la coordination de la production et du transport de l'électricité*
Therm. eff.: thermal efficiency
* Most of life cycle SO_x emissions from fossil fuel fired plants are emitted from the fuel combustion at generation plants. These emission factors are highly influenced by the power plant either with FGD and SCR facilities or without them. As a result, wide range of values for SO_x are indicated in this table.

1 Large scale hydro.
2 Small hydro (< 10 MW), not necessarily run-of-river.
3 Values for energy crops cycle in different countries.
4 Value for the forestry residue fuel cycle, transportation of 100 km round-trip
5 Range of data includes different cell types, roof mounted.
6 1st value for integrated gas combined cycle, 2nd for atmospheric fluidized bed combustion.
7 Values for Austria in 1990.
8 Projected values for UCPTE countries in 2005-2015.
9 Transmission and distribution included.

Table 13: ***Life-Cycle SO_2 Emissions (t SO_2 / TWh) (2/2)***

	North America (cont'd)				
Electricity Generation Options (classified by level of service)	**Canada, SECDA, 1994**	**Canada, FFCC, 1995**	**Canada, Theoretical calculations, Bélanger, 1999**	**USEPA, AP-42, 1998 & 1999**	**Comments**
Options capable of meeting base load and peak load					
Hydropower with reservoir	7				Refurbishment instead of dismantling can almost reduce emissions by 50%. Values highly dependent on site characteristics.
Diesel			84 / 836 [13]	1 285 [18] (plant only)	
Base load options with limited flexibility					
Hydropower run-of-river	1				Refurbishment instead of dismantling can almost reduce emissions by 50%. Values highly dependent on site characteristics.
Bituminous coal: modern plant	1 783	1 018	373 / 1 726 [14]	2 637 to 32 321 [19] (plant only)	
Lignite old plant			4 347 / 31 941 [15]	2 764 to 8 293 [20] (plant only)	
Heavy oil without scrubbing			8 013 [16]	9 595 [21] (plant only)	
Nuclear	3				
Natural gas combined cycle turbines	4	413	1 500 / 15 000 [17]	2 [22] (plant only)	
Large fuel cell (nat. gas to hydrogen conversion)	6				
Biomass: Energy plantation	26 [10]			4 to 81 [23] (plant only)	Values are highly dependent on wood quality and on conditions of exploitation (transportation distance, etc.).
Biomass: Forestry waste combustion	12 / 29 [11]				
Intermittent options that need a backup production (such as hydro with reservoir or oil-fired turbines)					
Windpower	21 / 69 [12]				Values highly dependent on turbine capacity, life, and site use factor. Values do not consider emissions from required backup production.
Solar photovoltaic	24				Values highly dependent on sun exposure. Values do not consider the emissions from required backup production.

10 Poplar plantation. (Data is site specific, not averaged.)
11 1st value for soft wood waste, 2nd for loggin residue. (Data is site specific, not averaged.)
12 Class 7 & 6 wind sites. (Data is site specific, not averaged.)
13 If 0,17% S in diesel and 32% thermal efficiency at plant, and with 90% scrubbing. (Not life cycle.)
14 If 0,5 and 5% S in coal, 35% thermal efficiency at plant and with 90% scrubbing. (Not life cycle.)
15 If 0,5 and 5% S in coal and 30% thermal efficiency at plant. (Not life cycle.)
16 If 1,5% S in oil and 32% thermal efficiency at plant. (Not life cycle.)
17 If 0,5 and 5% H2S in gas and 45% therm. effi. at plant with 95% removal during purification. (Not life cycle.)
18 Thermal efficiency 35% and 0,25% S.
19 Thermal efficiency 35% and 0,5 & 5% S.
20 Thermal efficiency 35% and 1% S.
21 Thermal efficiency 35% and 2% S.
22 Thermal efficiency 45%.
23 Thermal efficiency 42%.

Table 14: ***Life-Cycle NO_x Emissions* (t NO_x/TWh) (1/2)***

		World		Europe				North America
Electricity Generation Options (classified by level of service)	**Range of Life-Cycle Values**	**IEA, "Benign Energy?" 1998**	**ETSU, UK, IER and Enco, 1995**	**Switzerland, PSI, Dones et al., 1996**	**UK, ETSU, Bates,[10] 1995**	**Austria, IAEA, Vladu, 1995**	**Germany, ÖKO-Inst., Fritsche, 1992**	**USA, NDCEE, 1997**
Options capable of meeting base load and peak load								
Hydropower with reservoir	3 to 42	3 to 13 [1]						
Diesel	316+ to 12 300				12 300			
Base load options with limited flexibility								
Hydropower run-of-river	1 to 68	68 [2]						
Bituminous coal: modern plant	700 to 5 273+		1 000/700 [6]	1 400 [7]	2 928	1 050	700	
Lignite: old plant	704 to 4 146+		704				800	
Heavy oil without scrubbing	1 386+							
Nuclear	2 to 100				15		100	
Natural gas combined cycle turbines	13+ to 1 500		13 (plant only)	280 [8]	494	1 500	800	
Large fuel cell (nat. gas to hydrogen conversion)	0,3+ to 144							0,3 to 14 (plant only)
Biomass: Energy plantation	1 110 to 2 540	1 110 to 2 540 [3]						
Biomass: Forestry waste combustion	701 to 1 950	1 950 [4]						
Intermittent options that need a backup production (such as hydro with reservoir or oil-fired turbines)								
Windpower	14 to 50	20 to 36	36					
Solar photovoltaic	16 to 340	200 to 340 [5]		150 [9]				

Acronyms :

FGD : flue-gas desulfurization
SCR : selective catalytic reduction
UCPTE: *Union pour la coordination de la production et du transport de l'électricité*

* Most of life cycle NO_x emissions from fossil fuel fired plants are emitted from the fuel combustion at generation plants. These emission factors are highly influenced by the power plant either with FGD and SCR facilities or without them. As a result, wide range of values for NO_x are indicated in this table.

1 Large scale hydro.
2 Small hydro (<10 MW), not necessarily run-of-river.
3 Values for energy crops cycle in different countries.
4 Value for the forestry residue fuel cycle, transportation of 100 km round-trip.
5 Range of data includes different cell types, roof mounted.
6 1st value for integrated gas combined cycle, 2nd for atmospheric fluidized bed combustion.
7 Values for Austria in 1990.
8 Projected values for UCPTE countries in 2005-2015.
9 3 kW.
10 Transmission and distribution included.

Table 14: ***Life-Cycle NO_x Emissions (t NO_x/TWh) (2/2)***

	North America (cont'd)					
Electricity Generation Options (classified by level of service)	**USDOE, Argonne National Laboratory, 1992**	**Canada, Hydro-Québec, Gagnon, 1999a**	**Canada, SECDA, 1994**	**Canada, FFCC, 1995**	**USEPA, AP-42, 1998 & 1999**	**Comments**
Options capable of meeting base load and peak load						
Hydropower with reservoir		11	42			Refurbishment instead of dismantling can almost reduce emissions by 50%. Values highly dependent on site characteristics.
Diesel					316 to 758 [14] (plant only)	
Base load options with limited flexibility						
Hydropower run-of-river			1			Refurbishment instead of dismantling can almost reduce emissions by 50%. Values highly dependent on site characteristics.
Bituminous coal: modern plant			1 235	919	1 225 to 5 273 [14] (plant only)	
Lignite: old plant					995 to 4 146 [14] (plant only)	
Heavy oil without scrubbing					1 386 [14] (plant only)	
Nuclear			2			
Natural gas combined cycle turbines			459	416	256 to 944 [15] (plant only)	
Large fuel cell (nat. gas to hydrogen conversion)	< 110 (plant only)		144			
Biomass: Energy plantation			1 396 [11]		268 to 1 460 [16] (plant only)	Values highly dependent on conditions of exploitation (transportation distance, etc.).
Biomass: Forestry waste combustion			701 / 1 380 [12]			
Intermittent options that need a backup production (such as hydro with reservoir or oil-fired turbines)						
Windpower			14 / 50 [13]			Values highly dependent on turbine capacity, life, and site use factor. Values do not consider emissions from required backup production.
Solar photovoltaic			16			Values highly dependent on sun exposure. Values do not consider the emissions from required backup production.

11 Poplar plantation. (Data is site specific, not averaged.)
12 1st value for soft wood waste, 2nd for loggin residue. (Data is site specific, not averaged.)
13 Class 7 & 6 wind sites. (Data is site specific, not averaged.)
14 Thermal efficiency 35%.
15 Thermal efficiency 45%.
16 Thermal efficiency 42%.

It is therefore normal that studies arrive at a wide range of results.

Understanding the Results of Studies on NO_x

Studies on NO_x emissions can also arrive at a wide range of results, but these variations are more dependent upon combustion technology than on fuel:

- Most NO_x emissions are caused by the fact that oxygen is required for any form of combustion and that the main source of oxygen is ambient air, which is composed of 79% nitrogen (N). Therefore, the conditions of combustion are the main determinant in the level of NO_x emissions.

- Technologies that involve compression of air, such as diesel engines, will normally produce high level of NO_x emissions.

- The main exception to the "combustion rule" is coal, where significant amounts of nitrogen are also part of the fuel, thereby increasing NO_x emission factors.

Main Findings Concerning Acid Precipitation

Emission factors for hydropower and nuclear energy are hundreds of times less than those of coal based power generation systems without scrubbing.

Considering both SO_2 and NO_x, coal, oil and diesel based generation systems are important contributors to acid precipitation.

Biomass has a low emissions factor for SO_2 but a very high factor for NO_x. It is therefore a significant source of acid precipitation.

Natural gas, when considering the processing of fuel and NO_x emissions, can also be a significant source of acid precipitation.

The benefits of windpower are dependent upon network conditions and more difficult to assess. If windpower reduces the use of oil fired plants (which themselves can compensate for wind fluctuations), there would result a reduction in net emissions; however, in some cases, implementation of windpower may increase the use of oil-fired plants (as backup).

3.3.5
Contributions to Photochemical Smog: Life-Cycle NO_x Emissions and Volatile Organic Compounds (VOC)

Environmental Issues

Volatile organic compounds are complex molecules of hydrocarbon, which contribute, in conjunction with NO_x, to numerous chemical reactions in the lower atmosphere. Such reactions are accelerated by sunlight and are the source of increased levels of tropospheric — or low level — ozone and of other toxic/carcinogenic chemicals (Godish, 97, p. 38-42). The main sources of smog come from the transportation sector.

Standards for tropospheric ozone are regularly exceeded in many large cities and neighboring regions, with significant health impacts. Moreover, the ozone "cloud" can persist for many days, and damage forests and crops.

Emissions factors for NO_x are presented in the previous section. Considering that NO_x emissions are responsible for both smog and acid precipitation is not a "double-counting" mistake. This is due to the fact that NO_x emissions are used as a catalyst in the formation of ozone, but the nitrogen oxide molecules are not eliminated from the atmosphere. These molecules are then involved in slower chemical reactions that will produce nitric acid. So if conditions are favorable (e.g.: a hot sunny day and the presence of VOCs), NO_x emissions can contribute both to the formation of ozone and of nitric acid.

When the nitrogen returns to the ground as nitric acid, it can lead to other impacts such as the formation of excess nitrogen in forest soils, which in turn can affect the balance of nutrients needed by trees. Or else the nitrogen can be washed out into lakes and rivers, with potential effects on aquatic life.

As with SO_2, it is impossible to establish a direct link between NO_x and VOC emissions and the relative impacts of air pollutants. To create serious smog problems, many conditions are required: sunlight, heat and relatively high concentrations of NO_x and VOCs. Because of this, the actual health impacts can be totally different depending upon conditions. The location of fossil fueled power plants is a key issue relative to this environmental problem.

Understanding the Results of Studies on Emissions of "Non-Methane Volatile Organic Compounds" (NMVOC)

The following table presents the results of studies on "non-methane volatile organic compounds" (NMVOC). The exclusion of methane is required because even if it can be considered as a volatile organic compound, it is much less "reactive" than other VOCs, thereby contributing very little to the formation of tropospheric ozone.

Main Findings Concerning Photochemical Smog

Emissions factors for hydropower and nuclear energy are hundreds of times less than those of fossil fuels based power generation systems.

Any form of combustion can contribute significantly to smog if it is located in a region with many other sources.

Table 15: ***Life-Cycle NMVOC Emissions (t/TWh)***

Electricity Generation Options (classified by level of service)	Range of Life-Cycle Values	Europe: Switzerland, PSI, Dones et al., 1996	Europe: UK, ETSU, Bates,[1] 1995	Europe: Germany, ÖKO Inst., Fritsche, 1992	North America: USA, NDCEE,[2] 1997	North America: Canada, FFCC, 1995	North America: Canada, SECDA, 1994	North America: USEPA, AP-42, 1998 & 1999	Comments
Options capable of meeting base load and peak load									
Hydropower with reservoir									
Diesel	1 570		1 570						
Base load options with limited flexibility									
Hydropower run-of-river									
Bituminous coal: modern plant	18 to 29		29			18		7 to 19 [3] (plant only)	
Lignite: old plant									
Heavy oil without scrubbing	22+							22 [3] (plant only)	
Nuclear									
Natural gas combined cycle turbines	72 to 164	96	132	100		164	72	37 [4] (plant only)	
Large fuel cell (nat. gas to hydrogen conversion)	65				31 (plant only)		65		
Biomass: Energy plantation Biomass: Forestry waste combustion	89+							89 [5] (plant only)	Values highly dependent on wood quality and on conditions of exploitation (transportation distance, etc.).
Intermittent options that need a backup production (such as hydro with reservoir or oil-fired turbines)									
Windpower									Values do not consider the emissions from required backup production.
Solar photovoltaic	70	70							Values highly dependent on sun exposure. Values do not consider the emissions from required backup production.

1 Transmission and distribution included.
2 Methane emissions might be included in value.
3 Thermal efficiency 35%. (Total organic compounds)
4 Thermal efficiency 45%. (Total organic compounds)
5 Thermal efficiency 42%. (Total organic compounds)

3.3.6
Emissions of Particulate Matter (PM)

Environmental Issues

A small portion of fuels like coal and heavy oil is not combustible ("ash content"). This leads to emissions of particulate matter. Such emissions can also be caused by incomplete combustion of fossil fuels or by transformation of sulfur emissions.

Particulate matter is often referred to as PM10, meaning of a size of less than 10 microns. Recent studies have focused on very small particles (PM5), because the smaller particles seem to have much more effects on respiratory health.

Standards for particulate matter are regularly exceeded in large cities. The main sources of particulate matter are generally coal combustion and diesel fuel used in the transportation sector.

Compared to other pollutants, there is a more direct link between the concentration of PM10 and respiratory health.

Understanding the Results of Studies on Particulate Matter Emissions

The following table presents the results of life-cycle analysis. Results vary greatly for coal, depending on combustion and scrubbing technologies.

Main Findings Concerning Particulate Matter

Coal and biomass have very high emission factors, compared to other options.

Without scrubbing technologies, the emissions from coal and biomass can be hundreds of times higher than emissions from the full cycle of hydropower or natural gas turbines.

Windpower and solar photovoltaic have significant emissions during the manufacture of materials.

Table 16: ***Life-Cycle Total Particulate Matter Emissions (t/TWh)***

Electricity Generation Options (classified by level of service)	Range of Life-Cycle Values	World: IEA, "Benign Energy?" 1998	World: ETSU, UK, IER and Enco, 1995	Europe: UK, ETSU, Bates,[6] 1995	Europe: Germany, ÖKO Inst., Fritsche, 1992	North America: USA, NDCEE, 1997	North America: USDOE, Argonne National Lab., 1992	North America: Canada, SECDA, 1994	Comments
Options capable of meeting base load and peak load									
Hydropower with reservoir	5							5	
Diesel	122 to 213+			122		213 (plant only)			
Base load options with limited flexibility									
Hydropower run-of-river	1 to 5	5 [1]						1	
Bituminous coal: modern plant	30 to 663+		160 / 30 [5]	190	100	663 (plant only)		185	
Lignite: old plant	100 to 618		618		100				
Heavy oil without scrubbing									
Nuclear	2			2				2	
Natural gas combined cycle turbines	1 to 10+			1		10 (plant only)			
Large fuel cell (nat. gas to hydrogen conversion)	2 to 6+					6 (plant only)	4 (plant only)	2	
Biomass: Energy plantation	190 to 212	190 to 210 [2]						212 [7]	Values highly dependent on wood quality and on conditions of exploitation.
Biomass: Forestry waste combustion	217 to 320	320 [3]						217/254 [8]	
Intermittent options that need a backup production (such as hydro with reservoir or oil-fired turbines)									
Windpower	5 to 35	5						35	Values do not consider the emissions from required backup production.
Solar photovoltaic	12 to 190	140 to 190 [4]						12	Values highly dependent on sun exposure. Values do not consider the emissions from required backup production.

1 Small hydro (<10 MW), not necessarily run-of-river.
2 Values for energy crops cycle in different countries.
3 Value for the forestry residue fuel cycle, transportation of 100 km round-trip.
4 Range of data includes different cell types, roof mounted.
5 1st value for integrated gas combined cycle, 2nd for atmospheric fluidized bed combustion.
6 Transmission and distribution included.
7 Poplar plantation; Assumption of a sustainable harvest.
8 1st value for soft wood waste, 2nd for loggin residue.

3.3.7 Emissions of Mercury (Hg)

Environmental Issues

Mercury is present in the natural environment because volcanoes are a major source of airborne Mercury. Over the last decades however, anthropogenic sources of Mercury have exceeded natural sources. The main anthropogenic sources are coal and oil combustion, metal smelters and waste incinerators. Because of these activities, concentration of Mercury in Northern soils have doubled or tripled in the last decades.[1]

Hydropower is also concerned with the issue of Mercury. After flooding, the organic matter in reservoirs stimulates the activity of bacteria that turn inorganic Mercury into organic Mercury via methylation In its organic form, Mercury is assimilable in the food chain. Monitoring of reservoirs in Canada and Finland has demonstrated that Mercury accumulation in fish peaks after five to ten years and decreases thereafter, returning to normal in 20 to 30 years.[2]

Mercury can be ingested by local populations when fish is a part of their diet. Long-term exposure to toxic levels of methylmercury can translate into health problems. However, monitoring of this health issue is simple and mitigation is possible by controlling fish consumption (as it is done in Northern Québec).

Understanding the Results of Studies on Mercury Emissions

The following table does not show the results of life-cycle analysis. For fossil fuels and biomass, the data is for direct emissions at the plant only. For coal, it is normal to have a large range of emission factors because the Mercury content of coal varies substantially among coal types, at different locations in the same mine, and across geographic regions.

For hydropower, the factor produced in the table is not based on emissions: it is an estimate of Mercury that was returned to the biota after the creation of the reservoirs of the La Grande complex in Northern Québec.[3]

Main Findings Concerning Mercury Emissions

Among energy options, coal is clearly the largest emitter of Mercury. Heavy oil, biomass and natural gas also have significant emission factors, but these factors are several times smaller than typical factors for coal.

Per unit of energy, the rate of methylation of Mercury in hydro reservoirs is about 200 times less than typical emission factors of coal. Moreover, a portion of the Mercury that is returned to the biota by reservoirs came from fossil fuel combustion.

1 M.Lucotte et al., "Anthropogenic mercury enrichment in remote lakes of Northern Quebec", *Water, Air and Soil Pollution* 80:467-76, 1995.

2 J.-F. Doyon, R. Schetagne, 1999, *Réseau de suivi environnemental du complexe La Grande 1997-98.*

3 N. Thérien and K. Morrison, "Calculated Fluxes of Mercury to Fish in the Robert-Bourassa Reservoir", *Mercury in the Biogeochemical Cycle,* Springer, 1999, p. 259-72.

Table 17: ***Mercury Emissions at Plant (kg Hg/TWh)***

Electricity Generation Options (classified by level of service)	Range of Values	Europe: Switzerland, PSI, Dones et al., 1996	North America: Canada, Hydro-Québec, Gagnon,[2] 1999b	North America: Canada, Lui et al. Canadian Electricity Ass., 1994	North America: USEPA, 1997	North America: USEPA, AP-42, 1998 & 1999	Comments
Options capable of meeting base load and peak load							
Hydropower with reservoir	0,07		0,07				Net accumulation of total Mercury in biota, over a 6 year period after flooding.
Diesel							
Base load options with limited flexibility							
Hydropower run-of-river							
Bituminous coal: modern plant	1 to 360			103 to 360 [3]	1 to 131 [4]	14 [8]	Concentrations of Mercury in coal are highly variable, from region to region and even within a single stream. Emissions at plant also depend on the presence and efficiency of emissions control systems.
Lignite: old plant	2 to 42				2 to 42 [5]	23 [8]	Concentrations of Mercury in coal are highly variable, from region to region and even within a single stream. Emissions at plant also depend on the presence and efficiency of emissions control systems.
Heavy oil without scrubbing	2 to 13			13 [3]	2 [6]	3 [8]	
Nuclear							
Natural gas combined cycle turbines	0,3 to 1	0,3 [1]				1 [9]	
Large fuel cell (nat. gas to hydrogen conversion)							
Biomass: Energy plantation / Biomass: Forestry waste combustion	0,5 to 2				0,5 / 1,4 [7]	2 [10]	
Intermittent options that need a backup production (such as hydro with reservoir or oil-fired turbines)							
Windpower							
Solar photovoltaic							

Acronyms :

UCPTE: *Union pour la coordination de la production et du transport de l'électricité*

ESP: electrostatic precipitator

1 Projected value for UCPTE countries in 2010, thermal efficiency 57%.
2 Estimate based on study by N. Thérien & K. Morrison. 50 years of hydro production used in estimate.
3 Thermal efficiency 35%. (Theoretical calculations)

Means of measured values. Wide range due to variable Mercury concentrations in fuel and control systems:
4 Thermal efficiency 35%, with & without control.
5 Thermal efficiency 35%, with control.
6 Thermal efficiency 35%, typical emissions.
7 Thermal efficiency 42%, with ESP /without control.

Mean of measured values at 28 facilities burning bituminous coal (11), subbituminous coal (15) and lignite (2), with different control systems:
8 Thermal efficiency 35%.
9 Thermal efficiency 45%.
10 Thermal efficiency 42%.

3.4

INTEGRATION OF LIFE-CYCLE ENVIRONMENTAL IMPACTS

In the previous section (3.3), life-cycle environmental impacts were examined according to each major category of quantifiable impacts (e.g., GHG emissions, land area used, SO_x and NO_x emissions...). This, however, does not present the reader with a clear picture of the final effect of all of these categories of impacts. This section will try to present a wider view of cumulative life-cycle impacts of energy systems on human health.

The previous section also did not address some significant environmental issues that are difficult to quantify. One of these is the effect of hydro and biomass power generation on biodiversity. This is discussed further in section 3.4.2.

To describe cumulative environmental impacts, it is necessary to examine the various links between electricity generation and the “final health” of humans or ecosystems. This is also discussed further in the next two sections.

3.4.1 Integration of Impacts on Human Health

The cumulative impacts on human health are mostly related to atmospheric emissions. These are summarily described in the following table.

Table 18: ***Chain of Effects Between Each Pollution and Human Health***

First level pollution	Second level pollution	Third level pollution	Final impact on human health
SO_2 NO_x → →	→ Formation of acid H_2SO4 HNO_3 →	→ Washout of toxic metals (Al) from soils to rivers →	Impact on respiratory health Absorption of these metals by humans (through the food chain)
VOC + NO_x → →	→ Photochemical smog formation (notably 03) →	→ →	Direct toxic/carcigonic effects High toxicity
GHGs: CO_2 CH_4 →	Climate change →	Increased frequency of extreme events: floods / droughts →	Direct impact on the health of affected populations
Particulate matter	→	→	Direct impact on respiratory health
Toxic metals such as Mercury →	Contamination of soils, rivers and lakes →	→	Absorption of these metals by humans (through the food chain)

The next table presents, for each power generation system, the main health issues, including which chains of effects are relevant.

Table 19: ***Main Systems, with Final Impacts on Human Health***

Systems	Source of final significant impacts on human health
Systems capable of meeting base load and peak load	
Hydropower with reservoir	• Main issue: breach of dams • Risks from water-borne diseases, particularly when there is irrigation
Diesel	• Climate change • Acid precipitation • Photochemical smog • Particulate matter
Base load systems with some flexibility	
Hydropower run-of-river	• Main issue: breach of dams
Coal	• Climate change • Acid precipitation • Photochemical smog • Particulate matter • Toxic metals
Heavy oil	• Climate change • Acid precipitation • Photochemical smog • Particulate matter
Nuclear	• Radioactive substances
Natural gas turbines	• Climate change • Acid precipitation • Photochemical smog
Intermittent systems that need a backup production	
Windpower	• Depends on which backup system is used (oil or hydro)
Solar photovoltaic	• Depends on which backup system is used (oil or hydro)

3.4.2 Integration of Impacts on Biodiversity

Biodiversity issues are difficult to summarise because they can be expressed at many different geographical levels: a local pond, a river, a region, a biome or the planet. LCAs of energy systems must therefore clarify at which level an impact can become a biodiversity issue.

One author, Reed F. Noss, suggests that the assessment of biodiversity aspects be carried out according to three distinct scales[4]: within habitat, between habitat (including the "edge effect") and regional. The focus should be on ecosystems, and more specifically on preserving a network of ecosystems. Other authors also focus on the protection of ecosystems. J. Franklin[5] equally proposes that the protection of biodiversity be focused upon ecosystems, and not on individual habitats.

4 Reed F. Noss, "A Regional Landscape Approach to Maintain Diversity", *BioScience*, vol. 33 no. 11, p. 700-6.

5 Jerry F. Franklin, "Preserving Biodiversity: species, ecosystems or landscapes?", *Ecological Applications*, 3(2), 1993, p. 202-5.

For the generic assessment of energy systems (see following table), we will use the three following levels to assess potential biodiversity impacts:

- local and regional ecosystems: the various habitats directly affected by a project
- biomes: the largest ecological units, generally defined according to dominant vegetation
- genetic diversity at world level: the protection of endangered species.

For many energy systems, impacts on local and regional ecosystems may be site-specific. This is true for hydropower, but also for some fossil fuel based power generation. For example, the impacts of acid emissions will vary significantly according to ecological conditions. Any generalization must therefore be treated with care. Moreover, habitat modifications do not necessarily result in a loss of biodiversity. Even if hydropower does change terrestrial ecosystems into aquatic ecosystems, these new ecosystems may be very productive.

Table 20: ***Main Energy Systems, with Final Impacts on Biodiversity***

Generation Systems	Source of final significant impacts on biodiversity	Local and regional ecosystems	Biomes	Genetic diversity at world level
Systems capable of meeting base load and peak load				
Hydropower with reservoir	• Barriers to migratory fish • Loss of terrestrial habitat • Change in water quality • Modification of water flow	X X X X		
Diesel	• Climate change • Acid precipitation	X X	X	X
Base load systems with some flexibility				
Hydropower run-of-river	• Barriers to migratory fish	X		
Coal	• Climate change • Acid precipitation • Mining and transportation of coal	X X X	X	X
Heavy oil	• Climate change • Acid precipitation	X X	X	X
Nuclear	• Radioactive substances	X		
Natural gas turbines	• Climate change • Acid precipitation	X X	X	X
Intermittent systems that need a backup production				
Windpower	• Risks for some species of birds • Depend on which backup system is used (oil or hydro)	X (?)	(?)	(?)
Solar photovoltaic	• Depend on which backup system is used (oil or hydro)	(?)	(?)	(?)

3.5
CONCLUSIONS ON MAIN ISSUES

Even if social issues are important for many projects, including hydropower, they are not addressed in this chapter for the following reasons.

- Social issues are extremely variable from one project to another.

- "Generic" comparisons of systems are useful at the policy level where specific projects may not be known.

- The nature and importance of residual social impacts depend largely upon the nature and extent of mitigation and compensation programs, which may vary significantly from one project to another (or from one country to another).

Obviously, social issues must be integrated into the decision-making process. This process is discussed at length in the following chapters. Moreover, the comparison of energy systems on the basis of LCAs does not eliminate the need for political arbitration. This is due to the fact that many impacts are impossible to compare directly (e.g., local land use issues for hydropower or biomass energy plantations versus the management of radioactive wastes for nuclear power versus global and regional atmospheric issues for coal, oil and natural gas generation).

The different levels of impacts (e.g., global, regional and local) may be a good criteria to define priorities. Modifications to a global biochemical cycle (such as the carbon cycle) will ultimately produce important impacts on human health and biodiversity. Compared to local issues, such a global change is likely to be the source of more impacts. Carrying out environmental assessments on the basis of such levels of priority would clearly favor any renewable energy source over the various forms of fossil fuel power generation.

It is more difficult to give an overall conclusion on nuclear energy. Some groups will remain opposed to its development because of the issue of radioactive wastes. However, LCAs remain very favorable to this energy system.

Table 21 on the next page presents a summary of life-cycle impacts.

To conclude on the performance of hydropower, it is important to note that most comparisons of systems are unfair to hydropower for the following reasons.

- The multi-purpose character of reservoirs increase their environmental impacts, while the related benefits are often neglected.

- The reliability and flexibility that hydropower provides to the electricity network is often forgotten.

- Since "best available technology" is not an appropriate concept for hydropower, comparisons tend to compare statistics of old hydropower projects with new recent thermal power projects.

However, despite this "structural" negative bias, hydropower still comes out ahead of other energy systems in most comparisons.

Table 21: ***Synthesis of Environmental Parameters for Energy Options (Life-cycle Assessment)***

Electricity Generation Options (classified by level of service)	Energy Payback Ratio	Greenhouse Gas Emissions (kt eq. CO_2/TWh)	Land Requirements (km^2/TWh/y)	SO_2 Emissions (t SO_2/TWh)	NO_x Emissions (t NO_x/TWh)	NMVOC Emissions (t/TWh)	Particulate Matter Emissions (t/TWh)	Mercury Emissions (kg Hg/TWh)
Options capable of meeting base load and peak load								
Hydropower with reservoir	48 to 260	2 to 48	2 to 152 projects designed for energy production	5 to 60	3 to 42		5	0,07 methylmercury in reservoirs
Diesel		555 to 883		84 to 1 550	316+ to 12 300	1 570	122 to 213+	
Base load options with limited flexibility								
Hydropower run-of-river	30 to 267	1 to 18	0,1	1 to 25	1 to 68		1 to 5	
Bituminous coal: modern plant	7 to 20	790 to 1 182	4	700 to 32 321+	700 to 5 273+	18 to 29	30 to 663+	1 to 360
Lignite: old plant		1 147 to 1 272+		600 to 31 941+	704 to 4 146+		100 to 618	2 to 42
Heavy oil without scrubbing	21	686 to 726+		8 013 to 9 595+	1 386+	22+		2 to 13
Nuclear	5 to 107	2 to 59	0,5	3 to 50	2 to 100		2	
Natural gas combined cycle turbines	14	389 to 511		4 to 15 000+	13+ to 1 500	72 to 164	1 to 10+	0,3 to 1
Large fuel cell (nat.gas to hydrogen conversion)		290+ to 520+		6	0,3+ to 144	65	2 to 6+	
Biomass: Energy plantation	3 to 5	17 to 118	533 to 2 200	26 to 160	1 110 to 2 540	89+	190 to 212	0,5 to 2
Biomass: Forestry waste combustion	27	15 to 101	0,9+	12 to 140	701 to 1 950		217 to 320	
Intermittent options that need a backup production (such as hydro with reservoir or oil-fired turbines)								
Windpower	5 to 39	7 to 124	24 to 117	21 to 87	14 to 50		5 to 35	
Solar photovoltaic	1 to 14	13 to 731	27 to 45	24 to 490	16 to 340	70	12 to 190	

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4 REVIEW OF THE MOST EFFECTIVE MITIGATION MEASURES

4.1 INTRODUCTION

This chapter summarises both the biophysical and the socioeconomic mitigation, compensation and enhancement measures which have proven to be effective in hydropower projects over the years. The text is extracted from the technical report produced by Subtask 6 of Annex III[1] The Subtask 6 Report draws its information from the questionnaires submitted to a sample of power utilities from OECD countries, and particularly from Nordic countries. The text is also based upon a review of current literature[2] and completed on the basis of the professional experience of the contributors to the document and particularly of the participants attending Workshops no. 1 and no. 5 at the Madrid Technical Seminar in March 1999.

The following sections focus upon six major biophysical and four major socioeconomic concerns associated with building and operating hydropower, with a particular emphasis on associated mitigation, enhancement and compensation measures.

4.2 BIOPHYSICAL ISSUES

Basically, hydropower leads to the transformation of ecosystems by the creation of reservoirs and/or through important modifications to flow regimes. The nature and magnitude of impacts are highly site specific, vary significantly from one project to another and vary according to the biotopes in which projects are sited. However, most impacts can be reasonably mitigated if the project is correctly planned and designed. The most common physical and biological impacts observed following the analysis of the questionnaires and the literature review are linked to the following six major issues:

- reservoir impoundment
- loss of biological diversity
- reservoir sedimentation
- modifications to water quality
- modifications to hydrological regimes
- barriers for fish migration and river navigation.

The following section draws up, for each of the six main biophysical issues, the most common impacts of hydropower, as well as the most effective mitigation, compensation or enhancement measures that may be applied to reduce such impacts. As a general rule, mitigation measures can be grouped into three categories.

- At the outset, actions are taken to avoid impacts through proper planning and design.

- Once impact avoidance has been ensured to the utmost, mitigation measures and compensation for losses are then applied.

- And lastly, enhancement programs are put into place in order to improve upon initial conditions.

4.2.1 Reservoir Impoundment

The flooding of terrestrial, aquatic and wetland habitats following impoundment of reservoirs

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1 See: IEA May 2000. Annex III. Subtask III/6: "Hydropower and the Environment: Effectiveness of Mitigation Measures".

2 See: see: IEA. May 2000. "Hydropower and the Environment: Present Context and Guidelines for Future Action" Vol. III: Appendices:
- *Appendix D:* "*Physical and Chemical Environment*"
- *Appendix E:* "*The Flora and the Fauna*"
- *Appendix F:* "*Socioeconomic Environment*".

constitutes the main biophysical impact of hydropower projects. The operation of a power plant may lead to fluctuations of water levels within the reservoir and downstream which are different from those that occur naturally in lakes or rivers. For better understanding, it is useful here to distinguish physical modification from their biological consequences (for more details on biophysical impacts, see appendices D and E in Vol. III of this report).

Physical Modifications

- The transformation of terrestrial, wetland and aquatic environments into one large body of water leads to the loss of habitats, as well as to modifications of riparian and aquatic habitats.

- Sedimentation within the reservoir (see next section).

- Changes in water quality (see next section).

- Erosion of banks resulting from drawdown and increased fetch on large bodies of water.

- Fluctuations of water levels different from those observed in natural lakes lead to the destabilization of the drawdown zone.

Biological Consequences

- Repercussions on biological diversity (see next section).

- Changes in fish communities; as some species benefit from large bodies of water at the expense of swift current species.

- In certain cases, an increase in fish biomass as a consequence of the biological boom; in other cases, a decrease in fish biomass may occur as a consequence of eutrophication and/or oxygen depletion.

- Temporary increase of methylmercury in fish species in many reservoirs.

- Loss of spawning habitats. The importance of impacts on fish (positive or negative) depends upon the status of valued species for commercial, sporting or subsistence fishing).

- Loss of resources associated with riparian habitats or flooded habitats.

Impact Avoidance during the Planning and Design of Reservoirs

Reservoirs are one of the most important characteristics of most hydropower projects. Their presence on natural and human environment may have important positive and negative consequences. Appropriate measures are available to eliminate or reduce the adverse environmental effects of reservoirs and to optimize the positive ones.

Many reservoirs are used for different purposes, which include hydroelectric production, irrigation, flood control, fishing (commercial, sporting or subsistence), recreation, navigation, conservation of aquatic habitats or wetlands, etc. Adequate siting of a reservoir must take into account significant concerns, such as human population density, water quality, wildlife or wilderness reserves, national parks, valuable agriculture, valuable forestry, seismic activity, etc. The most impact avoidance action is to limit the extent of flooding.

The most effective measures to mitigate the impacts of reservoir impoundment are:

- minimize areas to be flooded as much as possible, on the basis of technical, economic and environmental concerns.
- reduce the water residence time in reservoirs, especially in tropical or subtropical environments.

Mitigating Measures During Construction

The most effective measures during the construction stage are related to compliance with relevant environmental laws, standards, regulations and codes of practice. These measures are most effective when systematically integrated into tender documents.

During or soon after construction, restoration techniques can usually be applied successfully for borrow areas and construction sites, by using indigenous plant species that are appropriate for the most extensively affected animal species. In addition, the clearing of timber zones before flooding in specific areas may be beneficial for certain types of aquatic or terrestrial habitats.

Impacts related to construction activities and to the opening up of new territories following the construction of new access roads are not specifically addressed herein. However, in some cases the presence of construction workers and visitors can be the source of significant tensions or conflicts with local communities who use the areas surrounding the project. Increased harvesting in such areas can imperil local wildlife resources and have an impact on local biodiversity. Such cumulative effects can be lessened by adequate control of new access roads, as well as by restricting fishing and hunting activities by project workers (see section 4.3).

Most Effective Mitigation, Compensation and Enhancement Measures for Aquatic Habitats

Once adequate planning has been carried out and the water quality of the reservoir has been ensured (see section below), other mitigation and compensation measures can be applied to reduce undesirable impacts associated with the reservoir.

Reservoirs generally constitute good habitat for fish. However, the impacts of reservoirs upon fish species will be perceived positively only if they involve species that are valued for their commercial use, or for sporting and subsistence fishing, and if there is no increase in fish contamination levels. New reservoirs can support new activities such as recreational navigation, sport or commercial fishing, and tourism.

The most successful measures for the development of fish communities and fisheries in reservoirs are the following:

- creation of spawning and rearing habitats
- stocking of adults or fries of commercial species that are well adapted to reservoirs
- access roads
- ramps and landing areas
- localized tree clearing prior to impoundment for navigation corridors and fishing sites
- navigation maps and charts
- recovering of floating debris
- fish farming technologies
- fish harvesting, processing and marketing facilities.

In the many cases where such events occur, there are no simple ways to prevent the temporary increase of mercury in fish in large reservoirs (Lucotte et al. 1999). Mercury and other contaminants must be monitored in fish harvested from the reservoir to comply with national marketing standards. Moreover, a risk management program should be set up to encourage locally affected communities to avoid consumption of contaminated species of reservoir fish, without abandoning their traditional lifestyles (Chevalier et al. 1997; Dumont et al. 1998). Such a program has proved to be successful for Aboriginal communities in Northern Québec (Canada).

Users may refuse to harvest reservoirs for ideological, cultural, religious or other reasons. In such cases, and also if water quality proves to be inadequate for aquatic resources, measures to enhance the quality of other water bodies for valued species should be implemented in cooperation with affected communities.

Once mitigation and compensation measures have been implemented in the reservoir, enhancement measures for aquatic habitats, or fishery enhancement programs, can be put into place in neighboring lakes and reservoir tributaries.

The most successful measures for the development of fish communities and fisheries beyond reservoirs boundaries are the following:

- creation of spawning and rearing habitats
- diversification of aquatic habitats
- opening up of new stretches of river with fishways, or reconfiguration of falls and rapids
- flow control devices, such as artificial riffles, dikes or weirs
- stocking of adults or fries
- installation of fish incubators.

The most successful mitigation, compensation and enhancement programs to restore terrestrial habitats are as follows:

- protection of land area equivalent or better in ecological value to lost land
- conservation of valuable land adjoining the reservoir for ecological purposes and erosion prevention
- creation of ecological reserves with rigorous and effective protective measures
- conservation of emerging forest in good areas for brood rearing waterfowl
- enhancement of reservoir islands for conservation purposes, such as units of floristic interest and colonial birds
- partial clearing of timber zones before flooding
- selective wood cutting for herbivorous mammals
- development or enhancement of nesting areas for birds
- installation of nesting platforms for raptors.

Effective Mitigation, Compensation and Enhancement Measures for Terrestrial Habitats

Reservoirs are created to the detriment of terrestrial and wetland habitats and resources, including terrestrial animals. Some measures may be very effective locally to create or protect specific habitats. Moreover, long term compensation and enhancement measures will be much more beneficial to the conservation of terrestrial habitats.

In certain reservoirs, large drawdown zones are not appropriate for habitat restoration. They may cause erosion and sedimentation problems that in turn may be the source of impacts on aquatic, riparian or terrestrial habitats. In order to minimize such effects, depending on local conditions, some measures to promote vegetation or control erosion can be applied following reservoir impoundment.

Measures to promote vegetation or control erosion following reservoir impoundment are summarized below:

- protection structures such as gravel embankments, riprap, gabions, etc.
- bioengineering for shore protection and enhancement
- banks restoration, including riparian vegetation enhancement (in some pumped-storage reservoirs, greening of large drawdown zones appears to be successful).

Landscape Adjustment and Heritage Amenities

A large number of measures are available to mitigate or compensate for landscape and vegetation losses and to protect or restore heritage amenities. Natural or cultural heritage areas are best protected through the proper planning and siting of reservoirs and construction areas. Mitigation measures involving landscape adjustment through afforestation and revegetation, combined with site decontamination and rehabilitation, are generally implemented on construction sites. In certain cases, such measures can also be effectively applied around the reservoir and in downstream areas. The cooperation of local communities and of national or regional authorities are key ingredients in the success of such activities.

Appendices A-1 and A-2 of Subtask 6 report list a number of examples of effective measures implemented under different climates. The most common are listed below:

- clearing the shorelines of the reservoir
- topsoil set aside during the exploitation of borrow pits
- transplantation of specific plant species
- construction of weirs to restore water level
- morphological adjustment of the land and revegetation.

4.2.2 Loss of Biological Diversity

Before considering any environmental measures affecting biological diversity, it is essential to define and understand the full significance of this concept in the context of an EIA.

To our knowledge, there is not yet one single definition of biodiversity on which the scientific community agrees. The term biodiversity, even when considered essentially according to its strictest etymological meaning (from the Latin *diversitas:* character, state of being different, and the Greek bios: life), remains a very complex concept. It is interpreted in different ways according to the field and the interests of the authors who have tried to define it. Accordingly, there are now many different definitions of biodiversity, which makes the understanding of this concept very difficult. How then is it to be taken into account in the context of an EIA?

The Convention on Biological Diversity (UNEP 1994) proposes this definition of the term biological diversity: *Biological diversity means 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.*

DeLong (1996), who analyzed 85 definitions of biodiversity, pointed out the broad range in which these various definitions can be contained, using the meaning of the two words that make up the term: life and diversity. It is important to point out that none of the definitions analyzed by DeLong, including the one he proposes, reflect its natural variability in time. All of the definitions treat it as if it were a stable state. To understand the real scope of this concept and evaluate the effect of taking biodiversity into account in EIAs, it is necessary to include the aspect of time in the basic definition, by pointing out that biodiversity is always in a state of constant change.

Thus, as was noted by Harms (1994) and Rodd (1993), none of the approaches proposed by various scientists for studying biodiversity have been actually put to the test. The authors also noted that is considerably easier to list the ways in which the concept of biodiversity has been incorrectly used than to present solutions with regards to the excessively complex problems of measuring and maintaining biological diversity. The challenge of applying such a concept becomes apparent whenever biodiversity is taken into account in an EIA without having first determined how to do so with all concerned stakeholders.

Given that EIAs for hydropower projects generally cover very large areas, studies are generally limited to the habitats of endangered or socioeconomically important species. It is then possible to assess the likely effects of building and operating the project on such habitats, and to determinewhether these effects may have significant consequences on biodiversity, as required by the Convention on Biological Diversity (CBD). In fact, similar information is required to assess the potential biophysical effects of a hydropower project and to identify the corresponding mitigation actions, independently of whether biodiversity must be taken into account or not. Therefore, any measures that may prevent or reduce the effects of hydropower projects on the habitats of endangered and socioeconomic species, in addition to all the other measures concerning habitats mentioned in this report, comply with CBD guidelines.

Whereas many natural habitats are successfully transformed for human purposes, the natural value of certain other areas is such that they must be used with great care or left untouched. Human societies can preserve environments that are deemed sensitive or exceptional, and the establishment of protected areas generally constitutes an effective means for ensuring the long-term viability of such environments.

The most effective steps to avoid loss of biological diversity are as follows:

- choose a reservoir site that minimizes loss of exceptional ecosystems
- try to limit as much as possible the size of reservoir, per unit of energy produced
- do specific inventories and acquire better knowledge on the fauna, flora and specific habitats within the studied zone
- protect an equivalent area to the flooded zone nearby the impacted zone
- keep intact a part of nearby ecosystem, assuming that unknown species will be protected.

4.2.3 Reservoir Sedimentation

Sedimentation is a major concern for the life-cycle of a reservoir. It has a direct influence on the costs and even on the feasibility of a hydropower project. The most common reservoir sedimentation problems are caused by the transportation by rivers of very high concentrations of suspended or entrained particles. Therefore, all potential sites for future reservoirs must be very carefully studied in order to correctly assess all of parameters that contribute to sedimentation. If excessive reservoir sedimentation is unavoidable, then appropriate attention must be paid during project planning to the provision of a storage volume that is compatible with the required life of the project (Alam, 1999).

If sediment loading occurs, it can be reduced by a) opening the spillway gates to allow for sediment flushing during flooding or by b) adding sluices to the main dam. Different sediment trapping devices have been used with success. Many approaches are also recommended by ICOLD (Stiger et al. 1989). However, protection of the natural vegetation in the watershed is one of the best ways to minimize erosion and prevent sediment loading.

The most effective mitigation measures to prevent reservoir sedimentation include the following:

- proper site selection
- precise knowledge about long-term sediment inflow characteristics to the reservoir
- adequate bank protection in the catchment area
- extraction of coarse material from the riverbed
- dredging of sediment deposits
- use of gated structures for flushing sediment with flow conditions comparable to natural conditions
- use of a conveyance system equipped with an adequate sediment excluder
- use of sediment trapping devices
- use of bypassing facilities to divert floodwaters.

4.2.4 Modifications to Water Quality

Water quality problems associated with the impoundment of reservoirs are the most difficult problems to mitigate. However, most of them can be reduced through appropriate project planning, design and management.

Because the reservoir constitutes the focal point for the watershed catchment, municipal, industrial and agricultural waste waters entering the reservoir contribute to increase water quality problems. In such cases, proponents and stakeholders must properly assess and manage this issue during all of the project planning, design, construction and operation phases.

The most frequent water quality problems within and downstream of reservoirs are summarised below.

Water Quality Problems within Reservoirs

- Dissolved oxygen depletion due to decomposition of flooded organic matter.
- Formation of anoxic deep waters layers in stable stratified environment.
- Water temperature changes.
- Increased turbidity associated to banks erosion.
- Concentration of waste waters and contaminants from the watershed and reservoir sediments.
- Eutrophication due to proliferation of floating aquatic weeds.
- Proliferation of waterborne diseases in shallow stagnant areas.

Water Quality Problems Downstream of Reservoirs

- Release from reservoirs of anoxic waters.
- Modification of the thermal regime.
- Gas supersaturation.
- Increased turbidity associated with banks erosion.
- Modifications to the flow regime.

Impact Avoidance during Planning and Design of Reservoirs

Most water quality problems can be avoided or minimized through proper site selection and design based on reservoir morphology and hydraulic characteristics. The objectives pursued are to reduce the area occupied by flooding and to reduce the water residence time in the reservoir.

Development schemes in high altitude tributaries (as opposed to flatlands) can reduce or prevent most water quality problems. Reservoirs located in cold oligotrophic environments may be completely devoid of water quality problems, even for schemes involving extensive flooding. In such environments, waterborne diseases are nonexistent and oxygen depletion is limited. In reservoirs located in sparsely populated areas or where land uses are limited, problems related to waste waters and contaminants may be avoided or easily mitigated.

Selective or multi-level water intakes may limit thermal stratification, turbidity and temperature changes both within and downstream of the reservoir. They may also reduce oxygen depletion and the volume of anoxic waters. The addition of structures for re-oxygenation to hydropower facilities has been used with success, mostly downstream of the reservoir. Downstream gas supersaturation may be mitigated by designing spillways, installing stilling basins or by adding structures to favor degassing.

Some specialists recommend pre-impoundment clearing of the reservoir area. However, this must be carried out carefully because, in some cases, a massive re-growth can occur prior to impoundment (Zwahlen, 1998).

During planning and design phase, the most effective measures to prevent water quality problems include the following:

- proper site selection
- use of selective or multi-level water intakes
- proper design of spillway or addition of structures to favor degassing
- addition of re-oxygenation devices.

Most Effective Mitigation, Compensation and Enhancement Measures during Construction and Operation of Reservoirs

Once appropriate project planning has been carried out and acceptable water quality within the reservoir has been ensured, residual impacts can be mitigated by additional measures. Watershed management which includes stakeholders is an effective means to share the responsibility of improving water quality.

The problems related to the decomposition of flooded organic materials in reservoirs (oxygen depletion and eutrophication) may be mitigated by vegetation and soil cover removal. However, such a measure can entail very high costs if the flooding is extensive, local vegetation is luxuriant or if the reservoir is located in remote areas. In tropical forests, increased oxygen depletion during impoundment due to rapid re-growth may appear after a complete removal of vegetation.

Increased water turbidity can be mitigated by protecting shorelines that are highly sensitive to erosion, or by managing flow regimes in a manner to reduce downstream erosion.

Planning periodic peak flows can increase aquatic weed drift and decrease suitable substrate for weed growth.

Waste waters and contaminants problems may be mitigated either by improving effluent treatment facilities or by improving agricultural practices. These measures could start before impoundment.

Mechanical and chemical treatment of shallow areas to reduce the proliferation of insects that are vectors of waterborne diseases may prove profitable but entail high costs and require delicate and continuous operations. Improvement of public health conditions in locally affected communities may prove to be more effective for waterborne diseases control (see: *Public Health Risks,* section 4.3.2).

During construction and operation phases, the most effective measures to increase water quality include the following:

- watershed management, including stakeholders participation
- pre-impoundment clearing when feasible
- shorelines erosion control
- mechanical and chemical treatment of shallow areas to reduce proliferation of insects carrying diseases
- mechanical elimination of waste and wastewater treatment
- prevention of excessive doses of fertilizers and pesticides in the watershed area.

4.2.5 Modifications to Hydrological Regimes

The operation of a hydropower plant generally involves modifications to the hydrological cycle downstream of reservoirs. In addition, certain projects involve rivers diversions that modify the hydrological cycle both upstream and downstream of reservoirs through a) the reduction of river flows downstream of the diverted site and b) the proportional increase of river flows along diversion routes. However, rivers with reduced or increased flows still follow a natural hydrological cycle.

Physical Modifications to Downstream Flow Regimes Resulting from Power Production

- Reduction of maximum flows and increase of minimum flows when discharge is regulated.
- Usually the flood discharge is stored in the reservoir, but depending on energy demand patterns, maximum flows resulting from power production may not occur at the same period of the year as the natural flood.
- Banks and river bed erosion resulting from a deficit in sediment loading.
- Reduction of the flood plain areas resulting from reduction of maximum discharge.
- Owing to fluctuations in electricity demand, important changes occur in water level on a seasonal, monthly or daily basis.
- If water level variations are small, a decrease in banks and river bed erosion usually occurs.
- If the short-term water level variations are large, an increase in banks and river bed erosion usually occurs.

Biological Repercussions Due to Modifications to Downstream Flow Regimes Resulting from Power Production

Biological repercussions do not always occur. Their occurrence or not is dependent upon the importance of physical modifications to downstream flow regimes. When they do occur, the following repercussions can be observed:

- Changes in water quality (see section 4.2.4).
- Loss or destabilization of riparian vegetation.
- Loss or destabilization of aquatic habitats.
- Loss of spawning and rearing habitats for fish due to changes in flow regime and water level fluctuations.
- Loss of aquatic resources.
- Loss of agricultural land associated with flood plains.

Physical and Biological Changes in Reduced-Flow Rivers Resulting from Diversion

- General decrease of water levels.
- Changes in river morphology and aesthetic qualities.
- Reduced aquatic habitats.
- Loss of fish resources.
- Increased salt intrusion in estuary.

Physical and Biological Changes in Increased-Flow Rivers Resulting from Diversion

- General increase of water levels.
- Changes in river morphology by increased erosion and sedimentation.
- Temporary reduction of riparian habitats.
- Increase of the freshwater plume in coastal areas.

Most Effective Mitigation Measures Related to Modifications of Hydrological Regimes

Downstream of control structures, flow regimes are different from natural discharges, both in terms of time and of volume. Physical and biological changes are related to positive or negative variations in water levels. The magnitude of these changes can be mitigated by discharge management: the smaller the short-term variations of water levels, the smaller the changes.

There is increasing pressure by regulatory agencies to incorporate a minimum ecological flow in the operation of water control structures. This minimum flow may be set for different purposes, such as: valuable fish species requirements, navigation, water quality, etc. It may also be necessary to create an artificial and controlled flood during a certain period of time to evacuate accumulated fine sediments or for other purposes. These requirements should be discussed, accepted and managed by a stakeholders committee.

The most effective mitigation measures related to modifications of hydrological regimes include the following:

- flow management by stakeholders
- banks restoration techniques
- fish habitat restoration programs
- protection of coastal habitats.

Once adequate flow management is achieved and water quality downstream of the reservoir has been ensured (see water quality section), some mitigation measures can be applied to reduce undesirable impacts. Most of them are related to banks restoration and fish habitats programs, the former having already been discussed.

Main banks restoration techniques include:

- planting and seeding
- protection structures such as gravel embankments, riprap, gabions, etc.
- bioengineering for shore protection.

River diversions lead to a general decrease of aquatic habitats. Instream optimum flow may be established at the design stage. The discharge can be constant or variable depending on the purposes; in the latter case, control structures must be added to the dam. These requirements should be discussed, accepted and managed by a stakeholders committee. The increased flow on diversion routes may call for additional restoration techniques that are summarised below. Major changes in the flow regime may entail modifications in the estuary where the extent of the salt water intrusion depends on the freshwater discharge. Another impact associated with dam construction is the decrease of sediment loading to river deltas.
As coastal plains are often intensively used for agriculture, fish farming and other activities, a rigorous flow management program must be ensured to prevent loss of habitats and resources. Here again, requirements should be discussed, accepted and managed by a stakeholders committee.

Other banks restoration techniques include:

- construction of weirs to prevent upstream salt intrusion
- construction of dikes to protect coastal habitats
- controlled floods in critical periods.

Finally, if significant residual impacts remain after implementation of all possible mitigation measures, additional compensation and enhancement measures can be designed and implemented in adjacent watershed catchment areas.

4.2.6 Barriers for Fish Migration and River Navigation

Hydropower dams create obstacles for the movement of migratory fish species and for river navigation. However, natural waterfalls also constitute obstacles to upstream fish migration and river navigation. Many dams are built on such falls and therefore do not constitute an additional barrier to passage. Most hydropower dams constitute a threat to fish during downstream migrations, by causing mortalities or injuries. As a general principle therefore, no hydropower dam should block the free migration of valuable fish species.

Impacts

- Barrier for migratory fish movement, upstream and downstream, causing:
  - reduced access to spawning grounds and rearing zones
  - decrease in migratory fish populations
  - fragmentation of non-migratory fish populations.
- Fish mortalities or injuries during downstream migrations.
- Barrier for river navigation.

Most Effective Mitigation Measures for Upstream Movement

Locks are the most effective technique available to ensure navigation at a dam site. For small crafts, lifts and elevators can be used with success. Navigation locks can also be used as fishways with some adjustments to the equipment. Sometimes, it is necessary to increase the upstream attraction flow. In some projects, by-pass or diversion channels have been dug around dams.

There are numerous examples of fishways and fish ladders, but their effectiveness is variable according to concerned fish species, the size of the river, the water head, design etc. However, it is the fishway design itself which is often not appropriate to the chosen site or to the concerned fish species. Effectiveness may be enhanced by adding leaders to guide fish to the fishway or fish ladder entrance. Other common devices include fish elevators, capture and transportation.

The most effective techniques to ensure upstream movement include:

- locks, lifts and elevators for crafts
- fishways, bypass channels, fish elevators, with attraction flow or leaders to guide fish to fishway
- fish capture and transportation.

Most Effective Mitigation Measures for Downstream Fish Movement

Most fish injuries or mortalities (adults and juveniles) during downstream movement are due to their passage through the turbines and spillways. Improvement in turbine design, spillway design or overflow design prove to be very successful to minimize fish injuries or mortalities. More improvements may be obtained by adequate management of the power plant flow regime or through spillway openings during downstream movement of migratory species.

Once the design of the main components (plant, spillway, overflow, flow management) has been optimized for fish passage, some avoidance systems may be installed (screens, strobe lights, acoustic cannons, electric fields, etc.). The effectiveness of such devices is variable, especially in large rivers. It may be more useful to recuperate the fish in the head race or upstream and transport the individuals downstream.

The most effective techniques for downstream fish movement include:

- improvement in turbine, spillway or overflow design
- management of flow regime or spillway during downstream movement of migratory fish
- installation of avoidance systems upstream the power plant
- fish capture and transportation.

Finally, if residual impacts still remain after implementing all the possible mitigation measures, fish stocking programs can always be designed and implemented as additional compensation and enhancement measures.

4.3
SOCIOECONOMIC ISSUES

To a greater degree than for their physical or biological impacts, the socioeconomic impacts of hydropower projects are largely conditioned by the nature of project-related mitigation measures and compensation packages and by the process leading up to their design and implementation. To a large extent, the actual design and implementation of socioeconomic mitigation measures and compensation packages determine whether a hydropower project becomes a means of *development and empowerment* or an instrument of *impoverishment and dependence.* Thereafter, a hydropower project can represent either a net gain or a net loss both for local communities and the regions to which they are connected. In most cases, however, hydropower projects generate a combination of economic and social gains and losses.

The most common socioeconomic issues observed following the analysis of the questionnaires and the literature review are linked to the following four major issues:

- involuntary displacement
- public health risks
- impacts on vulnerable community groups
- sharing development benefits.

The following section draws up, for each of the four main issues, the most common impacts of hydropower, as well as the most effective mitigation, compensation or enhancement measures that can be applied to reduce such impacts.

4.3.1
Involuntary Displacement

The most sensitive socioeconomic issue surrounding hydropower development revolves around involuntary displacement, which consists of two closely related yet distinct processes: a) displacing and resettling people and b) restoring their livelihoods through the rebuilding or "rehabilitation" of their communities. The reader is invited to refer to Volume III, Appendix F – *Socioeconomic Environment*, Chapter 6, for further discussion of this issue.

Impacts

There is a growing awareness about the adverse consequences of involuntary population displacement. The often-stated objective of rebuilding or restoring peoples' livelihoods is no longer considered satisfactory because displaced communities often experience declining standards of living for many years prior to project implementation. During the project-planning process, which in certain cases may take up to a decade or more, communities within the boundaries of the designated impoundment zone are confronted with problems associated with local public and private sector disinvestment. Faced with uncertainty, community members frequently stop to invest in local businesses or even to maintain their housing or farmland.

Where and when population displacement finally occurs, the severity of impacts is often considerable in terms of the numbers of people adversely affected, the vulnerability of such populations to resettlement, and the suffering caused both during and after removal from the impoundment zone.

Sadly, the proper management of these impacts has been largely neglected in the past by national and international development agencies because of inappropriate development policies, inadequate institutional and regulatory frameworks, insufficient financing, and biased design and planning methodologies. In many cases, capital cost overruns have led to completing the infrastructure at the expense of funds available for the resettlement and rehabilitation of displaced communities.

Funding and managing involuntary displacement is difficult for governments in the developing world, particularly in low-income countries confronted with land scarcity, competing needs and limited resources, as well as severe institutional capacity constraints. Moreover, the absence in many developing countries of effectively functioning land and labor markets, the substantive and procedural inadequacies of compensation systems for property appropriated by the state, and the absence of adequate social safety nets are three central reasons why the simple cash compensation of property losses under eminent domain laws cannot realistically be expected to provide satisfactory outcomes for displaced populations.

Perceptions regarding project-related involuntary displacement in developing countries are progressively changing due to the following factors:

- delays in project implementation and benefits foregone
- levels of destitution of affected persons in the past
- increasing concern about fundamental human rights and people's welfare
- impoverishment of people constitutes a significant drain on developing nations' economies.

Most Effective Mitigation Measures

As described in the World Bank's Resettlement Policy, in order to minimize or mitigate the social impacts of development projects, projects should be planned and implemented according to the following principles:

- *Avoid or minimise involuntary displacement:* The long-term economic and social costs of population displacement require that all possible means be explored from the onset to minimise such impacts.
- *Improve livelihoods:* The adverse social consequences of population displacement require that proponents ensure that all members of displaced communities are better off after the project than before the project.
- *Allocate resources and share benefits:* An excellent way to ensure that members of displaced communities are better off after the project is to provide such communities with long-term revenue streams based on benefit sharing mechanisms.
- *Move people in groups:* When communities must be displaced to make way for a project, it is recommended that community groups not be split apart in order to minimise the adverse social consequences associated with community dislocation.
- *Promote participation:* Decisions that may affect the livelihoods of the members of displaced communities must be openly discussed with and approved by concerned community groups.
- *Rebuild communities:* Displaced communities must be provided with the municipal and social services (transportation, energy, water, telecommunications, education and health services, etc.) required to ensure their long-term viability.
- *Consider hosts' needs:* Existing "host" communities that supply land and resources to settlers from displaced communities must be provided with the same benefits as those provided to displaced communities in order to avoid conflicts between "hosts" and "oustees".
- *Protect indigenous peoples:* Minimizing social impacts on indigenous or other culturally vulnerable communities requires that such communities be willing partners in the development of a hydropower project, rather than perceiving it as a development imposed by an outside agency with conflicting values. It also requires that local communities be given sufficient lead time to assimilate or think through the consequences of such a project and to define on a consensual basis the conditions in which they would be prepared to proceed with the proposed development.

According to the World Bank's review of its projects involving involuntary resettlement between 1986 and 1993, the major common factors which contribute to the success of resettlement are:

- political commitment by the Borrower, expressed in law, official policies, and resource allocations
- systematic implementation by the Borrower and the Bank of established guidelines
- sound social analysis, reliable demographic assessments, and technical expertise in planning for development-oriented resettlement
- accurate cost assessments and commensurate financing, with resettlement timetables tied to civil works construction
- effective executing organisations that respond to local development needs, opportunities and constraints
- public participation in setting resettlement objectives, identifying reestablishment solutions and in implementing them.

Involuntary displacement is viewed increasingly as a development issue and as such, resettlement programs should be built around a *development strategy.* This trend emphasizes the need to separate an infrastructure project's resettlement component from the infrastructure construction component. Resettlement programs funded with the assistance of international funding agencies are more and more frequently conceived as *stand-alone development projects* with discrete timetables and budgets.

A consensus is emerging to the effect that resettlement programs should ensure a *prompt and measurable improvement* of the lives of displaced people and host communities by:

- *Fostering the adoption of appropriate regulatory frameworks:* The regulatory and institutional aspects associated with resettlement are often difficult to address. Changes to legislative or institutional frameworks require the active involvement and commitment of the governments concerned.

- *Building required institutional capacities:* This addresses the need for an institutionalized project planning process; the need to ensure the participation of all groups affected by the projects in the decision-making process; and the need for reinforced local land management capabilities.

- *Providing necessary income restoration and compensation programs:* Experience indicates that cash payments to oustees in compensation for lost assets and revenues often leave project-affected people worse off. Therefore, losses incurred by individuals and communities as a result of project activities should be directly replaced and all compensation should, as far as possible, be in kind. Income restoration and compensation programs can be divided into two main categories: land-based and non-land based programs.

- *Ensuring the development and implementation of long-term integrated community development programs:* The administrative and financial management of the resettlement program must be coordinated through the existing network of regional social services located near the resettlement zone. Economic sustainability requires market proximity, sound natural resource management and including host communities as beneficiaries in the resettlement scheme.

New development strategies put forward for resettlement frequently emphasize *private ownership of resources* in rural communities in the developing world, as opposed to customary systems based on limited access to communal resources. A greater emphasis is also put on publicizing and disseminating project objectives and related information through *community outreach programs,* to ensure widespread acceptance and success of the resettlement process. Finally, the active participation of affected communities in the decision-making process is of the utmost importance.

4.3.2 Public Health Risks

Impacts

Hydropower projects, and especially large or major projects, affect hydrological systems as well as population densities. Higher incidences of waterborne diseases as well as of behavioral diseases linked to increased population densities are frequent consequences of the construction of a dam and the presence of a man-made reservoir, particularly in tropical or subtropical environments (Goldsmith and Hildyard, 1984; Hunter, Rey and Scott, 1982). The reader is invited to refer to Volume III, Appendix F – *Socioeconomic Environment*, Section 4.1, for further discussion of this issue.

Sadly, many tropical hydropower projects in the past have not taken into account the fundamental link between public health and economic development. The effects of large dams on public health have often been considered negligible in comparison to the benefits brought about by the constant availability of water and electricity.

Moreover, most of the health impacts related to large dams have been found to appear some time after the flooding of the impoundment zone. This has frequently allowed proponents to transfer the blame for poor local public health conditions by invoking inadequate public services, inappropriate hygiene practices or poor community management of newly available water resources.

In several countries, the absence of co-operation between agencies responsible for the design and implementation of such projects and public health officials has had serious consequences for locally affected populations. The management of outbreaks of diseases related to power and irrigation projects has in most cases been delegated to underfunded and structurally weak health care services.

Nevertheless, it is generally recognized nowadays – although not always put into application – that in order to ensure the long-term success of a hydropower project, public health impacts must be considered and addressed from the onset of the project. Efforts to mitigate public health impacts associated with large hydropower dam projects have until recently aimed to maintain local health conditions at the level of quality available prior to the project. It now appears that a consensus is emerging to the effect that hydropower projects should contribute to the improvement of public health conditions in affected communities.

To be able to attain such an objective, part of the costs of health care services should be included in those proposed water impoundment schemes which pose a risk to public health. Recurring costs for health education should also be included in the recurrent operational costs for such schemes. Health maintenance costs after the completion of an impoundment scheme could be partly supported from the gross income of that scheme. (Hunter, Rey and Scott, 1982).

The control of the health effects of excessive population increases around hydropower reservoirs requires managing the influx of migrant workers or migrant settlers from other localities and regions and minimizing to the utmost the flooding of inhabited areas. Imposing limitations on development around a reservoir cannot be undertaken without a strong governmental (or non governmental) planning agency responsible for adopting and implementing an efficient regional land use planning and control program to oversee and orient development.

To be effective, public health interventions associated with large hydropower dam projects must be designed and implemented on the basis of a holistic approach. Such an approach requires:

a) the establishment of a strong foundation, resting upon existing regional and local public health systems, and

b) the use of efficient tools, consisting of a series of diversified and project-specific mitigation measures.

Effective Mitigation Measures at the Planning and Design Stages

Measures required at the initial planning and design stages should:

- Aim to avoid or minimize public health risks at the very onset of the project.
- Aim at gaining a proper understanding of current health conditions and strategies for improving public health in the area selected for the siting of the dam.
- Provide from the onset for the inclusion of a health specialist in the project design team. To be effective, such a specialist must be given the necessary financial, administrative and technical support.
- Specific activities to be undertaken by the planning and design team and by the health specialist include:
  - planning the announcement of the project in order to avoid early population migration to an area not prepared to receive them (in terms of the presence of a local public health system)
  - establish an efficient communication network with national and local public health officials and specialists from NGOs
  - compile available data on local public healthconditions from the selected area to improve the project's design
  - develop a program of early interventions with national and local public health officials and specialists from NGOs to take into account foreseen population migrations
  - plan for the gradual implementation of disease prevention programs as soon as the project is announced.

Effective Mitigation Measures at the Construction Stage

Mitigation and compensation measures to minimise human health degradation brought upon by diseases during and after construction are numerous and well documented. Efficient measures include, amongst others:

- The design and implementation of waterborne disease vectors control programs, which generally involve both the suppression of potential vectors of disease and the control of stagnant waters.
- The introduction of easily accessible medical clinics and dispensaries in project-affected communities and in areas where population densities are likely to increase, the hiring and training of the required staff for these new facilities, and regular support for acquiring the drugs required for disease control.
- The containment and treatment of urban and industrial wastewater and air pollution around the reservoir.
- The design and implementation, by a team of specialists, of case detection and epidemiological surveillance programs to monitor changes to public health for local and regional populations.
- The design and implementation of public health education programs directed at the populations affected by the project.

Effective Mitigation Measures at the Operation Stage

Measures required at the operation stage aim to pursue the various mitigation measures initiated during the construction stage and to implement them in the daily lives of local populations. These include a series of monitoring and follow-up studies to ensure the long-term viability of local public health conditions.

More often than not, epidemiological problems occur only after the main construction activities are completed. Thus, the importance of ensuring the proper implementation of local public health programs initiated during the planning and construction stages.

In addition to pursuing measures that have already been initiated, some additional measures must be implemented to support public health interventions at the operation stage. These include:

- implementation of public health surveys to monitor general health conditions
- development of an epidemiological surveillance program
- use of appropriate irrigation infrastructures
- gradual implementation of locally adapted measures for the treatment and reduction of industrial wastewater and air pollution.

The effectiveness and durability of such an array of mitigation measures relies largely upon the capacity of existing public health care systems to ensure their proper implementation or, at the very least, to supervise and support them.

Required Performance Criteria for Regional and Local Public Health Systems

Attaining the capacity to eradicate waterborne or behavioral diseases and improve general public health requires that a public health system be able to respect several basic performance criteria. The criteria summarised below are derived from the study of tropical disease control programs that have been successfully implemented in developing countries (World Bank, 1991):

- Importance of relying on a coherent package of control technologies.
- Design of specific campaigns, subdivided into phases, with a solid organization and management.

- Capacity to rely heavily on expert staff groups that have the authority to decide on technical matters.

- Establishment of a clear line of authority supported by competent specialists providing technical support.

- System that is largely centralized in formulating strategy and decentralized in operations.

- System that understands the importance of fitting the organization to the task, not vice versa.

- Field systems that are reliable, efficient and realistic about what is feasible in peripheral regions.

- Emphasis on effective leadership and personnel management.

- Conscious effort to develop an organizational culture that fits with local specificity.

Although such efficient systems are not common or easy to establish, countries such as Zimbabwe, Egypt, Brazil, China and the Philippines have developed the necessary tools to implement them. If project planners cannot count on an organized and efficient national health system, they should at least design their project on the basis of a proper understanding of a) its potential effect on local health conditions and b) of the institutional support needed to implement adequate mitigation measures.

4.3.3 Impacts on Vulnerable Minority Groups

The World Bank describes indigenous peoples and ethnic minorities as "…social groups with a social and cultural identity distinct from the dominant society that makes them vulnerable to being disadvantaged in the development process…". The world view of a large number of traditional rural, agricultural or indigenous communities is built around the moral significance of their environment and the resources upon which they depend to live.

Impacts

Hydropower development projects in indigenous or traditional resource based areas can have far-reaching cultural and social effects at the community level. The extent of such impacts is difficult to ascertain, considering the number of outside influences to which they often are already subjected (encroachment on traditional land, extraction of local resources, migrant labor, schools, commercial exchanges, etc.). Nevertheless, such communities often perceive major transformations to their physical environment as being destructive to their culture (see Volume III, Appendix F – *Socioeconomic Environment*, Sections 5.2 and 5.4, for further discussion of this issue).

Changes to community traditions and ways-of-life brought about by hydropower projects can vary considerably from one project to another. For instance, the opening up of access roads to previously isolated areas for the construction of a hydropower dam may enable populations and goods to move more easily, offering new opportunities to exchange with other communities and a greater diversity and quality of available goods and services. On the other hand, improved access to the outside world may also lead to a loosening of social bonds and solidarity within the community, and to increased risks of competition or conflicts with outsiders for available resources.

Effective Mitigation Measures

It is very difficult to mitigate or fully compensate the social impacts of large hydropower projects on indigenous or other culturally vulnerable communities for whom major transformations to their physical environment run contrary to their fundamental beliefs.

Minimizing such impacts requires that local communities be willing partners in the development of a hydropower project, rather than perceiving it as a development imposed by an outside agency with conflicting values. It also requires that local communities be given sufficient lead time to assimilate or think through the consequences of such a project and to define on a consensual basis the conditions in which they would be prepared to proceed with the proposed development.

These conditions are not always easy to fulfill for outside development agencies. Thus, they are often tempted to press forward with project design for overriding national purposes, before obtaining the approval of locally affected communities. Instead of this, the objective for proponents should be to ensure that hydropower projects *provide sufficient time and resources to adapt to changing conditions,* as well as *alternative means to support traditional ways-of-life* where required.

The early involvement in project planning of respected members of affected communities is therefore essential to identify the communities' concerns and to work out locally beneficial solutions. For instance, such solutions may include proposals to compensate for losses of land and alternatives to existing sources of income that may be jeopardized by the project. In developing countries where local titles to land (particularly for indigenous peoples) are rarely available, legal protections can be granted by local governments so that affected communities retain exclusive rights to the remainder of their traditional lands and to new lands obtained as compensation.

Compensation for changes to community traditions and ways-of-life can be achieved to a certain extent through improved housing, education, social services and health care. However, such forms of compensation may not always be sufficient, particularly in the case of culturally vulnerable indigenous or ethnic minority groups that are largely dependent on locally available natural resources. Even in instances where such communities benefit economically from the introduction of a hydropower project, they often perceive the project as an implicit rejection of their cultural values. In such cases, ensuring the long-term financial support of activities that define local cultural specificities may also be required in order to minimize changes to community traditions and ways-of-life brought about by a hydropower project.

For instance, within the context of the James Bay hydropower projects in Northern Canada, the James Bay and Northern Québec Agreement signed in 1975 guaranteed exclusive hunting, trapping and fishing rights to local Cree and Inuit indigenous communities. It also enabled them to benefit from a government funded Income Security Program (ISP) for aboriginal hunters and trappers. This program provides benefits to community members who want to continue practicing a traditional lifestyle. The effects of the ISP for hunters and trappers on indigenous James Bay Cree communities have been studied by several social scientists (Salisbury, 1986; Scott and Feit, 1992; Proulx, 1992; Simard, et al., 1996). All of the studies indicate that the ISP has enabled these communities to maintain their traditional ways-of-life, or at least to slow the decline in the practice of such activities that had been observed before implementation of the James Bay hydropower projects, when compared to other indigenous communities that have not benefited from the ISP.

4.3.4 Sharing of Development Benefits

Impacts and Benefits

Because of their long-term structural impact, there is no doubt that well sited and designed hydropower projects have the potential to generate significant national and regional economic benefits. It is difficult to overstate the economic importance of hydropower and irrigation dams for densely populated developing countries that are affected by scarce water resources for agriculture and industry, limited access to indigenous sources of oil, gas or coal, and frequent shortages of electricity.

In many cases, however, hydropower projects have resulted both in winners and losers: locally affected communities have often born the brunt of project-related economic and social losses, while the regions to which they are connected have benefited from a better access to affordable power and to regulated downstream water flows and water levels. The reader is invited to refer to Volume III, Appendix F – *Socioeconomic Environment*, Chapter 3, for further discussion of this issue.

The major direct and indirect environmental and social costs of hydropower that are frequently borne by communities both within and downstream of the impoundment zone include:

- the submergence of valuable land and resources, and associated losses in tax income

- the reduction of downstream water quality and impoverishment of soils

- the long-term erosion of downstream river beds and estuaries and coastal erosion
- the reduced viability of subsistence agriculture and decline of downstream fisheries
- the overuse of other vulnerable environmental resources on less fertile inland soils
- increased long-term national debt burdens.

The major regional benefits of river flow regulation for downstream communities are related to flood control and to irrigation. Downstream river flow regulation and low flow augmentation are also likely to facilitate commercial and recreational navigation below the dam and within the reservoir. Even if the effectiveness of dam-related water management practices for ensuring flood control remains a subject of debate worldwide, the presence of dams upstream strongly encourages local populations to settle closer to the downstream river bed or within the limits of the flood plain. The presence of regulated river flows and low flow augmentations often support:

- the development of irrigated agriculture and cash crops
- the development of industries that require large and regular supplies of river water
- the development of various service industries that supply inputs to and market the products from agricultural and industrial concerns.

In turn, these new economic activities, often in combination with other factors, are liable to generate additional series of indirect or induced socioeconomic benefits and impacts, which become progressively more and more difficult to trace back to the original hydropower dam project. For instance, increased economic activity may attract an influx of migrants from outside the watershed and lead to greater downstream population densities and to the growth of new urban communities.

Optimizing the Regional Benefits of Hydropower

Ensuring a sustainable basis for electricity supply from hydropower requires careful planning that must be carried out in close cooperation with concerned stakeholders. Hydropower development generally provides inexpensive electricity which serves as a foundation for further industrial and commercial activities. Although economic benefits are often substantial, effective enhancement measures exist to ensure that local and regional communities fully benefit from the hydropower project. Some measures apply specifically to the construction phase of a project, others may continue throughout the operation phase.

Measures to optimize the regional benefits of hydropower include:

- Developing equity-sharing partnership solutions with local and regional institutions. These institutions may become part-owners of the power plant, ensuring direct profits for the region and a voice in the operating decisions.[3]
- Creating an environmental mitigation and enhancement fund, jointly managed by the power plant owners and the local and/or regional institutions.[4]
- Hiring a liaison officer to serve as the link between local communities and the hydropower project.
- Setting up a regional economic development committee between the power plant and the local / regional economic stakeholders (businesses, labour unions, chambers of commerce, economic development agencies, etc.) to inform, consult and discuss collaboration possibilities.

3 Example: the SOCOM (Société en Commandite), by Hydro-Québec

4 Example: the SOTRAC (Société des Travaux Correcteurs) by Hydro-Québec.

Measures to optimize the regional benefits of hydropower (cont'd)

- Splitting construction contracts, in order to allow smaller regional companies to bid.
- Encouraging large construction contracts to use local businesses to supply part of the services and/or equipment.
- Preferential hiring of local workers, directly for the construction work and/or for the ancillary services (road maintenance, catering, security, etc.) and indirectly through sub-suppliers.
- Providing training for local workers in order to improve their competence and chances of employment.[5]
- The design and implementation of river basin management plans that take into account the water needs of concerned stakeholders, in the reservoir area and downstream.
- Long-term efforts to develop and sustain reservoir fisheries and drawdown agriculture, as well as associated infrastructure and commercial and public services.
- In certain cases, new reservoirs can support such new activities as commercial fisheries, recreational navigation, sport fishing or tourism.
- To ensure that project-affected people actually become beneficiaries of new development schemes, training and technical assistance are required, as is the protection of the entry of project-affected people during the early years of such schemes.

5 See Corfa, G., Milewski, J. 1998. "Building social trust between developers and stakeholders: the case of SM3 in Québec". In *International Journal on Hydropower* & *Dams*. Vol. 5. Issue Three, 1998. p. 69-72.

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5 ETHICAL CONSIDERATIONS

This chapter presents the main ethical dilemmas faced by those involved in hydroelectric projects. Ethical dilemmas cannot be separated from the contexts in which they arise. The text begins, therefore, with some ideas which are essential background material to understand the context of ethical dilemmas and hence the dilemmas themselves. Next the chapter describes and categorizes the main dilemmas. It finishes by presenting several ethical principles that can help in the search for standards of conduct regarding hydropower development and the environment.

5.1 VALUE SYSTEMS

Ethics are guidelines imposed on personal conduct based on awareness of human values. The need to control behavior becomes an issue when one realizes that one's actions can have negative impacts on oneself or others.

The various schools of ethics differ in their explanation of what motivates the choice of one behavior over another. All, however, agree that human beings are capable of making choices and are responsible for their actions.[1] Managers of companies that produce hydroelectricity are aware of its benefits and drawbacks. They must also be able to weigh these against an acknowledged system of values and of sound ethical principles. This, however, is no easy task.

5.1.1 Differing Views of Human Relations

The view each person has of the relationship a human being should establish with the universe and with other human beings is part of a value system that forms his or her interpretation of "what is acceptable".

In the past, large-scale hydroelectric projects were considered highly attractive by political leaders, and many privately owned utilities were nationalized because of the perceived benefits they provided to society as a whole. During the last two decades, public awareness of environmental issues and impacts on human communities has increased and has created controversy over large-scale energy projects, including hydroelectric ones. The often conflicting positions on project validity and justification stem mainly from differences in the understanding of man's relationship with nature and in ideas about development, the rights of affected communities, relations between majorities and minorities and the distribution of decision-making power. These explanations are part of a coherent logical framework that convinces each and everyone of us of the correctness of our interpretations when discussing or deciding on the advisability of a project.

Where energy projects are concerned, several value systems are often involved. They are usually based on very different paradigms that map not only what is but also what ought to be done.

We outline below in very general terms some of these value systems, while highlighting those aspects that can lead to controversy and without considering ways of reconciling them. These value systems change gradually over time, and some values which were not as strongly felt three decades ago are more important today. This is also indicated below.

Managerial and Profit-Driven Value Systems

The vast majority of the world's hydro projects are owned by governments, central, regional or local. The value system that prevails within governments or parastatal organizations is to increase the welfare of the constituency, which can either be a country, the population of a state, or that of a smaller region. An important premise is that

1 Racine, Legault, Bégin.1991. *Éthique et ingénierie.* McGraw-Hill, Montréal, 1991, 285 p., p. 8 to 13.

growth in employment and material wealth is essential for the progress of humanity and the improvement of health and living conditions. Economic growth and creation of national wealth are thus part of the responsibilities of governments. All natural resources must be used with wisdom and good judgment to ensure their sustainability for future generations. Human activity is a means to enhance the bounties that nature provides, to increase both the quantity and the variety of foods and materials that man obtains from the natural environment. At the same time, the development of natural resources must be in harmony with nature to ensure a continuing supply of resources. The proponents of this value system believe that science and technology are essential tools for achieving society's economic and social objectives while ensuring that limits imposed by the ecosystem are not exceeded. For complex issues of a scientific nature, experts and specialists are best qualified to assess opportunities and risks, evaluate options and make technical decisions. For issues related to the competing demands of different segments of society, the political and legal systems are called upon to arbitrate and make decisions.

A small fraction of the world's hydropower installations are owned by private sector firms. Their value systems are oriented towards profitability and financial return on investment[2], while remaining within the legal and regulatory frameworks created by governments. Private firms may have differing corporate cultures and value systems. Many of them are managed by persons convinced of the needs of sustainable development, while others are not. Most of them are aware of the risks to their profits and their firms if they do not comply with environmental regulations.

Ecologically and Socially-Driven Value Systems

Another value system which has attracted increasing support during the past three decades maintains that nature should be disturbed as little as possible. Man is part of nature, and nature has intrinsic value that goes beyond the use to which it can be put by man. We must try to understand and respect natural cycles and live in harmony with them. Ecological systems are delicately balanced, and technological interventions can cause irreversible damage to the Earth's life-sustaining processes.[3]

There is also a value system, linked to the previous one, which promotes social relationships and community interaction, and increased participation by smaller groups within our society in decisions that affect our daily lives. It considers that the creation of material wealth is only one among many goals of our society and a high priority must also be given to social relationships and community, to the exercise of human skills and capacities, as well as to increased participation in decisions that affect our daily lives. This value system is associated with the increased global concerns over human rights in general, and specifically minority and individual rights.

Clearly, there is no consensus when it comes to codes of moral conduct. In our modern, cosmopolitan, multiethnic societies, we must learn to deal with this.

5.1.2 Ethics of Conviction, Ethics of Responsibility, Ethics of Discourse

Let us look now at three categories of ethics that may be helpful for the purposes of our discussion. The first, *ethics of conviction*[4], are for example, those of the militant, who makes decisions and organizes his life based on his convictions, which he believes to be paramount. This category of ethics is also labelled the "ethics of ultimate ends", referring to a teleological perspective of ethics in which a moral action is focussed on seeking good ends, regardless of the means that might be used to gain such ends.[5]

The second, *ethics of responsibility*, are, for example those of the manager, whose decision-making is based instead on analysis of the foreseeable consequences of his actions. This category of ethics

2 See ch. 2.4.1 *Trends for the Financial Viability of Hydropower Projects* for a detailed discussion about this aspect.

3 Cotgrove, Stephen F. 1982. *Catastrophe or Cornucopia: The Environment, Politics and the Future.* Chichester. John Wiley & Sons. p. 27-29.

4 Weber, Max. 1959. *Le savant et le politique.* Paris. Plon 10/18 no. 134. 184 p., p. 172.

5 Bolan, R. S., "The Structure of Ethical Choice." In M. Wachs, 1985. *Ethics in Planning,* Rutgers, pp. 74-75.

argues that there is an intrinsic rightness and wrongness in individual acts of human conduct. Good ends cannot be justified by wrong actions. One should forego good ends if they can only be achieved by wrong acts.[6]

Though advocates of the two categories are frequently in opposition, each group of ethics plays an essential role in society.

> Ethics of conviction cause new requirements to emerge, and spreading them through society, they become social facts. However, it belongs to the ethics of responsibility to judge their pertinence and to ensure their implementation.[7]

The third useful category of ethics is called *discourse ethics.*[8] According to advocates of this approach, ethics are possible only through and in discourse, that is, in argued dialogue that makes the development of thought possible thanks to certain rules. The ultimate goal is to find common ground that allows action with the help, or at least consent, of the different parties. Three fundamental criteria can be used to assess the validity of a given discourse[9]:

- Truth of the discourse's content;
- Accuracy of the discourse in a given normative context (legitimacy);
- Sincerity of the discourse (confidence of listener in what the speaker is saying).

In the context of hydropower developments, the latter criterion is a crucial one as it reflects issues such as social trust and perceptions in the decision-making process and the underlying struggle between conflicting interests.

Convictions, the achievements of science, a sense of realism and responsibility and a search for common ethical ground – all this must come into play in establishing the characteristics of an acceptable project. When we discuss further on the ethical dilemmas faced by project planners, we will draw on all three of these ethical approaches.

5.2 LEARNING FROM EXPERIENCE

Through stories and experience, human beings watch their societies evolving in action. The collective memory holds lessons, perceptions, that suggest benchmarks for evaluating the acceptability of a project and for identifying conditions for consent. The paragraphs below summarise three "collective images" or representations related to hydropower, that are prevalent today.

5.2.1 Water, a Precious Resource

The first image concerns water perceived as a precious and threatened resource. Fresh water is essential for human, animal and plant life. It is poorly distributed over the globe, rare in some areas and overabundant in others. In many countries there has been a shortage of water for millennia, in others increasing populations and increasing industrialization may lead to water shortages in the future. In almost all countries water use is regulated so that users can share the available resources, and maintain them both for current and future generations. The laws and regulations related to water vary from country to country. In many cases, water is considered to belong to society as a whole, whereas in others water rights are privately owned.

Whether the purpose is irrigation, drinking water supply, better navigation conditions, flood control or electricity generation for urban or industrial development, dams bring changes in water use and water distribution that can profoundly alter ecosystems and human activities. Given this, it is not surprising that many people feel strongly about the construction of dams.

6 *Ibid.*, pp. 74-75.

7 Beauchamp, André. 1996. *Gérer le risque et vaincre la peur.* Bellarmin. Montréal, 187 p., p. 99 (our translation)

8 Habermas, Jürgen. 1991, *Erläuterungen zur Diskursethik,* Frankfurt; Suhrkamp.

9 Healey, P. 1992. "Planning Through Debate: The Communicative Turn in Planning Theory". In *Town Planning Review,* 63. (2).

5.2.2
Dams Have Improved Living Conditions

The second collective image refers to dams as a source of wealth and pride. Human beings have been searching for ways to harness the force of rivers since the beginning of recorded history. The problems of protecting people against floods and of distributing and managing water resources have occupied governments since the earliest civilizations.[10] The oldest dam of which we still have vestiges dates back to 3000 BC. The use of water resources to produce electricity dates back about one century. For many, hydroelectric structures are a source of great pride and a symbol of economic progress.[11] The power they provide is essential to our civilization. In developing countries, most people aspire to education, better health, piped water and electricity, and the leaders of such countries are aware of the vital role that power in general and hydroelectricity in particular plays in economic growth and social development.

5.2.3
Dams Have Harmed Watersheds and Scattered Communities

The third image refers to dams as destroyers of rivers and communities. In this case, large dams translate into the disappearance of forest lands or fertile plains, the grip of powerful interests on the common heritage of less advantaged populations, the indignation and disillusion of vulnerable communities, and massive population displacement.[12] Controversies around such aspects have attracted increasing interest in academic circles and the possible harm which dams can cause to watersheds, cultures, and national economies has been extensively studied.

It is thus clear that hydropower developments evoke positive as well as negative memories accumulated over time. The collective memory of benefits and adverse effects stemming from dams is often loaded with feelings – fear as well as hope. These collective memories are partly shaped and reinforced by the media, forging long lasting but evolving images in the public's mind.

5.3
ETHICAL DILEMMAS

“Dilemmas” are proposals for action that are contradictory or very difficult to reconcile but that one must nonetheless choose between. Dilemmas relating to hydroelectric projects fall into four major categories: the protection of nature versus the satisfaction of essential human needs; distribution of wealth; the rights of affected communities; the diversity of rules and cultural differences.

5.3.1
Protection of Nature and Satisfaction of Essential Human Needs

Since the 70s, the public has become aware of major global environmental problems associated with increased energy consumption and development. In outlining the concept of sustainable development, the World Commission on Environment and Development (1988, p. 10)[13] stated that generalized poverty is not inevitable, that misery is an evil in itself. Sustainable development must provide an answer to the problems of poverty and injustice, make it possible to satisfy the essential needs of all and allow everyone to aspire to a better life.

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10 The oldest masonry dams in Europe, still in operation, are probably the 22 m-high Proserpina dam and the 24 m high Cornalbo dam in Spain, dating back to the 2nd century of the Christian era. (ref. Carrère A.J., Noret-Duchêne C. 1998.)

11 Egré, D., Klimpt, J-E., Milewski, J. (1997), *Le développement énergétique durable: des objectifs globaux pour une action régionale,* Communication Congrès Nikan, 13 p., p. 2.

12 McCully, Patrick, Silenced Rivers, *The ecology and politics of large dams* (1996). Zed Books, London &New Jersey, 350 p., p. 24.

13 CMED, in Beauchamp, A. *Introduction à l’éthique de l’environnement,* (1993), Editions Paulines & Mediaspaul, Montréal, Paris, 22 p. p.97.

In the name of justice, fairness and solidarity, several less developed countries resist international opinion and the discourse of countries of the North demanding that consumption be reduced and natural reserves protected because the biosphere is now sick from the growth of the developed countries. They claim the same right to human dignity and wealth as any developed economy, and point out that the 128 countries with low and medium-low levels of energy consumption per person contain three-quarters of the world's population but account for only a fifth of commercial energy consumption.[14] They suggest that the obvious place to reduce consumption and waste is in the industrialized countries, not in the developing ones. On the other hand, some people in developed countries, argue that the lessons learned from a century and a half of industrialization could prevent or at least minimize environmental and other mistakes made in the past.

Electricity has become an essential service in the fight against underdevelopment. Hydroelectricity offers a variety of options to meet electricity needs. It is based on a renewable energy cycle, often at a competitive cost, and can be coupled with suitable mitigation and enhancement measures. It affects river and terrestrial ecosystems and river valley populations, but it is also possible that the environmental benefits outweigh the costs. In some areas of China, for example, the substitution of electricity for firewood has led to an increase of forested area.[15]

Dilemma #1

How can we reconcile the development of hydroelectricity to meet the essential needs of the present and future generations with the necessity of maintaining healthy ecological systems? Is hydropower incompatible with productive ecosystems?

Dilemma #2

Natural habitats are affected to a greater or lesser degree by hydroelectric projects depending on the size and nature of reservoirs and the alteration of hydraulic regimes of developed rivers. Other sources of electricity, however, also have serious environmental impacts. They use fossil fuels and emit air pollutants and greenhouse gases that have local, regional, and global effects. Which is preferable?

Dilemma #3

Are we prepared to pay a potentially higher price for other forms of renewable electricity production (wind, photovoltaic) in order to mitigate the environmental impacts of current electricity generation? In a world of limited resources, who will pay for the added costs, and at the expense of what other priorities?

Dilemma #4

Is it fair to limit the development choices of less developed economies by severely restricting hydropower development on the basis of its environmental and social impacts, when developed countries have greatly benefited and still do from the abundant and inexpensive electricity[16] *it can provide?*

14 The World Conservation Union (IUCN), United Nations Environment Program (UNEP), World Wide Fund for Nature (WWF) (October 1991). *Caring for the Earth, A strategy for Sustainable Living,* Gland, Switzerland, p. 45.

15 Tong Jiandong. 1997. *Small Hydro Power: China's Practice.* International Network on Small Hydro Power. Hangzhou, PRC. p. 13-14. and p. 48-49. Before rural electrification, firewood took up 66.5% of the total energy consumption of Dehua County, in Fujian Province, coal 10.4% and electricity 7.7% while through 5 years' effort of electrification, the percentage of electricity has increased to 68.5%, and that of coal and firewood reduced to 1.8% and 12.5% respectively. The electrification efforts have also increased the forest coverage from 50 to 70%. Forest coverage in the 208 counties which participated in the Rural Electrification Programme of the 8th Five Year Plan increased from 29.7% to 33.8%.

16 For example Canada has an installed capacity of 65,000 MW of hydropower producing 2/3 of the country's electricity for decades to come (source: ICOLD, IHA, 1997), at low cost compared to other existing forms of power generation.

5.3.2 Distribution of Wealth

Some of the dilemmas in this category arise no matter what the source of energy, because they all generate revenues which are distributed in varying proportions to the various stakeholders. Hydroelectricity does produce revenues and wealth, and its distribution is an issue, as local populations might bear environmental and social costs, while the customers of the electricity benefit from the energy.

It would be interesting, to map over time and space the problems of distribution of wealth created by collective resources used to produce electricity, taking into account the main externalities associated with each energy source. Such a study would give us a better understanding of ethical issues associated with electricity generation in general and identify those associated with hydroelectricity in particular.

Dilemma #5

Who "owns" water resources? Is it the local community in which a hydro project is built, is it private individuals or corporations, or the people living in the watershed, a regional or national government or a combination of the various alternatives? What if a river flows through several countries? What is the legitimacy of using a local resource – the hydropower potential of a river – for the benefit of larger constituencies such as a country, an industry or urban dwellers?

Dilemma #6

How should the revenues from a hydroelectric project be shared? What are the respective rights of the various stakeholders – developers, governments, local communities, affected individuals and others – and how should these rights translate into revenue-sharing or other arrangements such as land rights?

5.3.3 Rights of Affected People

Many "run-of-the-river" hydro projects result in limited inundation of land. Other hydro projects are located in sparsely or unpopulated areas, such as high alpine sites or deserts. However, certain reservoirs have led to the displacement of communities or the loss of livelihoods, as well as the flooding of land including forests and farmlands. Resettlement programs have often been unsatisfactory. Affected groups have spent years claiming their right to fair compensation and an equitable resettlement.

The hydropower project responsible for the flooding has often generated large revenues, produced electricity and/or irrigation water, and has helped to achieve major social goals. In view of these benefits and the revenues generated, the groups which are negatively affected because of inadequate resettlement programs often feel a strong sense of injustice.

Many types of projects require significant resettlement of people living in the targeted areas[17]; these include industrial parks, suburban expansion, urban renewal projects, highways, airports, harbor construction projects, national parks, water resource projects, etc.

During the past three decades, there has been a shift in value systems in that the rights of the affected individuals or groups have obtained a much higher priority than was the case in the past. When aboriginal peoples are affected, their legal rights and title to large areas of land are often controversial, but public opinion increasingly tends to be in favor of fair and generous settlements. Aboriginal communities often have sacred ties to the land. Breaking these ties can lead to acculturation and social disruptions. An entire culture and its traditions can be threatened but it is not always easy to determine what is irreversible and what is not.[18]

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17 The World Bank. Environment Department. April 8, 1994. *Resettlement and Development: The Bankwide Review of Projects Involving Involuntary Resettlement.*

18 Such as the Waimiri-Atroari case of an indigenous nation affected by the controversial Balbina reservoir in the Amazon basin, where the native population is thriving following a successful social development program initiated in collaboration with the dam promoter, while other villages of the same nation are suffering from disruptive mining activities nearby (source: Documentação Indigenista e Ambiental, 1998).

Today, community agreement to resettle, and a strategy to improve the living standards of the displaced people are considered prerequisites. It is legitimate that all who lose homes, land or livelihood be compensated.[19] In practice, however, implementing successful resettlement policies is difficult. Large scale projects of this nature can involve bureaucratic inefficiencies and in some cases corruption. Affected populations are entitled not merely to promises of compensation, the promises have to be carried out fully in a timely and efficient manner. There may also be substantial groups of people who are not directly affected in the sense that their property are in areas which will not be flooded, but who are nevertheless affected by changes in river regimes. Such changes can be beneficial or adverse, depending on the circumstances. People who benefit, for example from protection from floods, usually do not have to pay for this benefit. People who are negatively affected, for example from increased risk of water borne diseases, must sometimes adjust to profound transformations of their lives without being entitled to compensation.

Other sources of electric power also have human impacts. Extraction and transport of fuel entail all the impacts and major risks of mining, transportation and shipping: displacement of populations, fuel spills, industrial diseases, risk of explosion or collapse, etc.

Dilemma #7

What weight should be given to the adverse effects of displacement of populations when compared with the benefits of the particular proposed project? How far do the rights of a community go given the number of individuals it represents, and how should this be weighed against the benefit of a project given the number of individuals whose situation will improve?

Dilemma #8

In some projects – particularly those involving resettlement – it is impossible to avoid cultural, historical, archeological, aesthetic and emotional losses for the affected population. How can one compensate losses which are very significant but generally non-quantifiable? How can one judge the extent of the negative impact on a displaced population, particularly when their culture or even their capacity to survive is threatened?

Dilemma #9

Should we choose electricity generation options, such as natural gas, that might minimize local social impacts even if they produce greater global environmental impacts than hydropower?

5.3.4 Diversity of Rules and Cultural Differences

Environmental and social standards and the expectations of developers differ from one country to the next. What some people feel essential is not necessarily guaranteed or promoted to the same extent in all countries by legislation or regulatory frameworks. Ethical dilemmas stemming from the diversity of rules and cultural differences are not restricted to hydroelectric energy; such dilemmas are fundamental and they also apply to hydroelectric projects.

Many international hydro projects are financed by means of public funds, either export credits or foreign aid, from one or more industrialized countries, or from a development bank such as the World Bank. The latter has developed sets of environmental and social guidelines, and many developed countries impose their own environmental and social rules on international projects, even if they are not required by the host country. In addition, some non-governmental organizations are asking that an international code of water resource management with force of law be adopted. The stated goal is to create a regulatory framework that will guarantee protection of the environment, democratize and decentralize the decision-making process for water resource and land-use management agencies and force countries to inform and involve affected communities.[20]

19 San Francisco Declaration, in McCully Patrick, *op.cit.*, p. 313.

20 San Francisco Declaration, Manibeli Declaration, in McCully Patrick, *op.cit.*, p. 315, p. 319.

Countries have different cultures, different value systems, different forms of government, and different priorities. Developing countries have far fewer choices, and may, for example, be forced to clear certain forest areas in order to grow food for agriculture or even survival, as was done in developed countries in the past. In many countries, economic growth and social development pushed by poverty and population growth may have a much higher priority than environmental protection.

Decision-making processes regarding major projects depend strongly on the form of government and the political institutions and traditions in each country. The extensive public consultations which have become common in developed countries during the past three decades are less frequent in most other countries, and communities affected by a hydro project generally do not participate in high level decision-making. The manager of a hydro project is often in a difficult position, faced with a diversity of interpretations of environmental and social issues, those accepted in the countries investing in the project, those of the host country, and those of non-governmental organizations, local and international.

Dilemma #10

With regard to environmental issues, should international standards prevail over local laws and traditions? To what extent can international rules, guidelines, or codes of management be practically applied? By whom?

Dilemma #11

When considering the rights of affected populations, should international standards prevail over local laws and traditions? To what extent can international codes of practice with respect to good governance, public disclosure, public participation and legal recourse be practically applied? By whom?

5.4
ETHICAL PRINCIPLES

Any ethical analysis of the impacts of a planned hydroelectric project needs to be based on its specific context, the use to which the project will be put, the wealth it will generate, the distribution both of this wealth and of the water that is stored behind the dam, and the impacts on the local population and the environment.

We will now briefly look at five ethical principles that can guide decision-makers in their search for rules of conduct when faced with the dilemmas described above. By and large, in International and Comparative Law, authors agree on the five following principles as a basis for analysis (see Chapter 6). These are: entrusting and stewardship; participatory decision making; prudence and control; fairness and justice; optimality.

5.4.1 Entrusting and Stewardship (responsible management)

Stewardship covers two concepts: man's responsibility to nature and the need for prudence, or caution, in managing natural resources. From the moment we became aware of the tremendous increase in our power to destroy or provoke alteration in major terrestrial ecosystems we once took for granted, a new ethical imperative emerged: man's responsibility towards the Earth's life-sustaining systems.

Stewardship supposes consciousness of the fragility of the biosphere and care in managing our heritage so that today's generation can meet its needs without compromising satisfaction of those of future generations. "Un héritage dégradé dégradera en même temps les héritiers" [21]. The survival of man cannot be separated from the survival of nature. Stewardship means wise, careful

21 "A degraded heritage will also degrade the heirs" (our translation) in Jonas, Hans (1990), *Le principe responsabilité. Une éthique pour la civilisation technologique.* Paris, Cerf, 336 p., p. 302.

and responsible management of resources, as opposed to arrogant and disrespectful domination of nature in the name of man's lordship over the world around him which was characteristic of the industrial revolution.

A good steward has the trust of his principals who delegate to him, in accordance with certain rules and for a period of time only, their legitimate decision-making authority because they recognize his competence to make decisions in their names and interests. Stewardship demands a system of checks and balances that guarantees periodic validation by all principals of the soundness of measures considered for managing the common heritage.

5.4.2 Participatory Decision Making

During the past three decades citizens have increasingly challenged the power and authority bestowed on their elected officials and the bureaucracy. For major decisions which affect communities and the environment, they want a decision making process which is transparent and informs and consults not only those who are immediately affected, but also a wide range of interest groups. The rights of the individual and small groups have gained strength, the rights of the majority and governments are not as strong as they used to be.

The developers of hydro projects have to deal with this new political reality, and it does not always make their task easier. Participatory decision making can have positive results in that important factors which might otherwise be overlooked are taken more fully into account. The final decision will also carry more weight and have more moral authority and legitimacy if it is based on a transparent and participatory process. It can also have negative effects if concerned stakeholders are not properly represented. Our value system has evolved and those who are governed want to participate more fully in decisions made by those who govern.

5.4.3 Prudence and Control

Prudence and control are associated with the concept of responsibility mentioned above. It is a question of caution and far-sightedness in uncertain situations: don't act if serious effects are probable, do act to prevent serious deterioration of the environment.[22]

When technology is put to work – for hydroelectric projects, among other things – there is no complete certainty either about the expected benefits or about the scope of negative impacts, especially the long term impacts. Decision makers do not have the luxury of complete information, and have to take calculated risks. Scientific analysis of impacts helps decision-makers to minimize these risks, based on experience and knowledge of facts. However, an unforeseen negative impact may require corrective action later. Prudence demands in-depth risk assessment for all the major issues such as environmental impacts, safety of populations, the spread of disease, and the effect on displaced communities. In each case, careful judgments have to be made whether the magnitudes of adverse impacts can be considered to be acceptable or not.

To exercise prudence, a manager must have the necessary tools to learn from experience and to monitor and control the impacts of his work as they appear. This way, he will be in a position to react in a timely manner to unforeseen impacts.

5.4.4 Fairness and Justice

Although the controversial hydro projects represent only a small proportion of the total, they have raised and continue to provoke strong feelings. In part, this stems from a perceived imbalance between the benefits they bring to urban populations, major industrial consumers and certain elites on the one hand, and the harm done

22 O'Riordan, Timothy and Cameron, James (1994) *Interpreting the Precautionary Principle.* Earthscans Publications Ltd. London, p.18. (315 p).

to the most disadvantaged members of society on the other. In some countries governments deal harshly with opponents, and this may increase international indignation. Often the issue is not so much the physical hydroelectric project itself as the social and political structure of the area where it is located. Social and political tensions which existed before are brought to the surface by major projects which require large areas of occupied land, such as urban expansion, road construction, or hydro projects.

In liberal democracies it is generally agreed that human societies are cooperative ventures whose purpose is to bring mutual benefits in the interests of the greatest number without infringing on the rights of individuals or small groups. However, putting this principle into practice is difficult. The social contract set forth in laws and regulations is the first tool in administering justice; this is why it is crucial to ensure that it includes the regulatory frameworks necessary to protect the environment and guarantee respect for the rights of affected populations.

Experience shows that the code alone may not be able to guarantee justice, that it must be complemented by guidelines for action. Sustainable development demands that one act with respect for human dignity and for the right of every human being to develop his or her potential. In our opinion, this means that the benefits and drawbacks of a project that transforms natural resources must be analyzed for fair distribution within and between generations. Those who draw benefits from the project must also support the costs and the risks. Fairness also means that affected individuals that do not receive direct benefits should be compensated fully.

Identifying impacts and determining their intensity is crucial to allocating just compensation or gains. Reality, however, is interpreted according to personal or corporate values, and these tend to come into play here. In other words, a participatory decision-making process is necessary to determine what is fair. The most equitable solutions generally arise from discussions that give everyone a chance to be heard within a well-structured process.

5.4.5 Optimality

The acceptability of a project depends on the desirability of the alternative selected relative to others considered. Optimality is the selection of the best option given all factors considered important including technical, economic, social and environmental factors.

In selecting a technology or alternative for an electricity generation project, comparison of feasible alternatives using criteria that represent the interests of as real a spectrum as possible of the parties concerned will show the advantages and drawbacks of each alternative and the trade-off to be made. The difficult balancing of pros and cons in the search for an optimal solution is a rewarding experience that tends to generate the trust a manager will subsequently need to execute his project in an atmosphere of social peace. It will deepen the understanding of all aspects of the situation and be helpful in the subsequent execution of the project. The demands of various stakeholders are often competitive or even contradictory, but if all stakeholders are aware of the demands of the others and have seen the need to make compromises, they may consent to the selection of the best option under the circumstances.

Project goals and justification are the first things looked at when evaluating the acceptability of consequences. They must be clearly expressed so that possible impacts can be measured against goals pursued – and relative failure and success can be determined and adjustments made if necessary.

Selecting the “best option” also implies analyzing and comparing valid alternatives. Experience shows that this is often difficult for several reasons: The technical or economic complexities of a project must be simplified to be accessible to all stakeholders, which is not always easy. The question of who is a legitimate representative of a group or a stakeholder and hence be entitled to participate is not always an easy one. Some participants, including the promoter, may have strategies of all sorts to promote an alternative selected in advance. A small group may advance their interests at the expense of society as a whole, and there might not be a spokesperson for society as a whole at the table. Transparent, participatory processes need to be carefully structured in order to ensure their fairness and to arrive at a satisfactory outcome. Optimality of the social aspects of a project, however, demands a full discussion of the interests of all stakeholders.

5.5 CONCLUSIONS

Discussions of ethical principles are often considered theoretical, without practical implications. The global environmental and social problems we face, however, have provoked acute awareness of the interdependence of human communities and the need for solidarity. Sustainable development as a recognized principle of human activity requires that equal consideration be given to the protection of human rights, the right to economic development and the protection of the environment.

Both the benefits and the costs of dams have a value in the eyes of those involved, but sometimes such values are difficult or impossible to measure or quantify. One benefit is that some dams have saved thousands of lives which were lost to floods before the dam was built, but how does one measure the value of these lives? One cost is that some dams have relocated thousands of people from the area to be flooded, but how does one measure the cost of such disruption? In fact, the value systems which were described earlier are composed of many values which cannot be readily measured or easily compared. Yet in our daily lives we are often required to make choices among competing values, and we make these judgments based on the priorities that are a part of our value system. The ethical analysis is more difficult in the case of hydroelectric projects because the people affected have different value systems, and these values evolve over time.

We have tried to suggest some ethical approaches that can guide the search for solutions to ethical dilemmas that hydroelectric projects raise both at the international and domestic levels. A review of all 11 of the dilemmas cited will show that a legitimate and fair decision-making process, guided by the above-mentioned principles, should be a sound approach to resolve the conflicting views with respect to hydropower. Other issues which are not included in the 11 dilemmas will continue to arise, and if they are considered in the light of these ethical principles, an important first step towards their solution will be made.

The following chapter on “Legal and Regulatory Framework” will link the ethical principles presented here to the legal mechanisms developed for the Environmental Assessment (EA) process. The final chapter, “Summary and Recommendations ” will suggest specific guidance to solve some of the dilemmas identified above.

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6 LEGAL AND REGULATORY FRAMEWORK

6.1 INTRODUCTION

The preceding chapters of the Subtask V Working Group Report discussed the various types of hydropower projects (Chapter 1), recent trends in hydropower development (Chapter 2), the comparative environmental impacts of available power generation options (Chapter 3), the specific environmental and social impacts of hydropower (Chapter 4) and ethical considerations related to hydropower (Chapter 5). Environmental approvals processes for hydropower projects are addressed in the present Chapter 6. This chapter presents the various legal mechanisms or instruments that apply to hydropower projects in various countries, identifies problems associated with these mechanisms or instruments, briefly discusses best practices, and draws a few conclusions in order to improve existing practices and regulatory frameworks.

The Subtask IV Working Group prepared detailed questionnaires to gain a better understanding of the legal and regulatory context for hydropower development in various countries. They submitted them to participating countries in the Annex III Reports (mainly OECD members) who voluntarily filled out the questionnaires and returned them to the Subtask IV Working Group. Subsequent workshops, reviews of literature and consultations with members of the various Annex III Working Groups provided additional information and examples.

As noted previously in Chapter 5, ethical dilemmas frame hydropower development issues. Thus, to be of any use, an assessment of environmental approvals processes for hydropower projects should take into account ethical considerations. From a legal perspective, the ultimate goal is to reconcile the three principles that frame hydropower development:

- promoting human rights
- protecting the environment, and
- ensuring everyone's right to economic development).

Harmonization among these principles can be attained by pursuing a holistic approach, while taking a sustainable development perspective. As our review of the literature has shown, this method proves effective in reconciling the opposing views of parties involved in environmental approval processes, by balancing the different concerns of local populations, of groups promoting environmental conservation and of project proponents.

Chapter 6 outlines and discusses environmental approval processes in the specific context of hydropower projects in the next millennium. More than ever in the future, a decision-making process must not only aim at reconciling stakeholders perspectives, it must also be efficient[1] and effective[2] for stakeholders and for society at large. An efficient process is one which minimizes the resources required – time, money, expertise – to achieve a decision. An effective environmental process is one in which the environmental and social impacts of a project are correctly and rigorously assessed.

Four sections make up this chapter.

- The introduction (6.1) relates this chapter to the previous ones and summarises the content of the different sections.

- Section 6.2 presents the method and objectives of our analysis of existing legal mechanisms. We wanted to get quickly to the point and not delve too much into theoretical concepts of comparative law. For concision, the first two subsections of 6.2 are presented in greater detail in Appendix H, I and J of Volume III. The first subsection presents a review of literature assessing environmental impact assessment processes. The second discusses principles of international environmental law and sustainable develoment. The third subsection sums up the first two and

1 Based upon an assessment of the time and effort involved, where effort is linked to the costs of the environmental impact process.

2 Based upon an assessment of whether the EA has produced the intended result, including whether all relevant impacts associated with a proposed activity have been adequately identified, assessed and fully taken into account in decision making.

outlines the choices we have made. It is called *Five Common Ethical Principles as a Common Ground for Analysis.*

- Section 6.3 is titled *Analysis, Findings and Assessment of Legal Mechanisms,* echoing Chapter 5 on ethical considerations.

- Finally, section 6.4 summarises our analysis and gives recommendations in order to improve existing practices and regulatory frameworks.

6.2
METHOD AND OBJECTIVES

Two approaches coexist world-wide for examining environmental impact assessments (EA). The first is the comparative law approach, known as the hard law approach. It is based on a comparison of the EA systems and legal mechanisms used in different countries. The second is the soft law approach. It is used in international environmental law to study international agreements, treaties, declarations and such, and to identify common trends in the evolution of environmental law and EA processes.

6.2.1
Review of Literature Assessing Environmental Impact Assessment Processes

Many organizations and authors have assessed legal mechanisms and EA processes. We reviewed their work to decide the best way to carry out our analysis. Appendix H sums up our review and conclusions.

6.2.2
Principles of International Environmental Law and Sustainable Development

As in 6.2.1, we reviewed works by authors and organizations at the international level to decide the best approach to adopt to meet our goals and expectations. Appendix I sums up our review and conclusions.

6.2.3
Five Common Ethical Principles as a Common Ground for Analysis

Assessing EA processes is a complex task that requires going beyond the concepts of effectiveness and efficiency. Indeed, any analysis that did not bear ethical principles in mind would be incomplete. Our analysis therefore also considers whether legal mechanisms are based on ethical principles and whether the mechanisms respect ethical standards. The criteria used for our assessment are the five ethical principles outlined earlier:

- optimality
- stewardship
- fairness and justice
- participatory decision making
- prudence and control.

In addition, we considered information gathered from working groups, seminars, case studies and the past experience of the members of IEA's Annex III: Hydropower and the Environment.

There is a growing international consensus on basic ethical principles, although there are still some substantial differences on their interpretation. Many such principles have been included in conventions signed and ratified by numerous countries. They have also been integrated into customary international law. Appendix J presents some examples of such integration of ethical principles in international law.

Another justification for our approach – taking into account ethical considerations to assess EA processes – is found in the basic philosophy of law, where the fundamental distinction lies between positivist law (law is law) and natural law (law should not be distinct from ethics; it is a means to achieve justice). These two concepts are not mutually exclusive but rather complementary. This is even truer in the field of environmental law.[3]

3 Michael R. Anderson shares this view of the interdependency between national and international rights. He says that the enormous number of international regulations adopted in the past years makes it impossible for national systems to ignore the "network of global standards," particularly concerning environmental protection. (See Alan E. BOYLE and Michael R. ANDERSON,(1996) *Human Rights Approaches to Environmental Protection*, Oxford University Press, p. 18.)

The positivist law approach describes and analyzes legal mechanisms in force, while the natural law tradition incorporates ethical principles into legal mechanisms. Such a dichotomy is also evident between national law (which is closer to positivist law since it defines and enforces legal mechanisms) and international law (which is closer to natural law since it describes ethical principles in international declarations and conventions). Increasingly, authors agree that the challenge in the environmental sector is to incorporate more ethical principles into the positivist law of nation-states and to assess whether EA legal mechanisms comply with the five ethical principles outlined in Chapter 5.[4]

In addition, hydropower projects frequently involve ethical dilemmas, as previously explained (see Chapter 5). Indeed, some actions may be contradictory or very difficult to reconcile. Though it involves difficult decisions, producing power is necessary to support economic development projects and the well-being of the population. As stated, four major categories of ethical dilemmas stand out: the protection of nature versus the satisfaction of essential human needs; the distribution of wealth; the rights of affected communities; and the diversity of rules and cultural differences. In a comparative law perspective, these dilemmas are analyzed on the basis of the protection of human rights, the right to economic development, and the right to a healthy environment.

6.3
ANALYSIS, FINDINGS AND ASSESSMENT OF LEGAL MECHANISMS

This section comments on the effectiveness and efficiency of the mechanisms in light of the five ethical principles mentioned above. The project stages listed below (policy context, planning, implementation, operation, upgrading, relicensing and decommissioning) are phases that are generally accepted in hydropower development at the international level. Theses phases or stages are described in more detail in Appendix K of volume III.

The legal mechanisms listed were drawn up from information gathered by the Subtask IV Working Group in its questionnaires. Other contributors working on this report also provided input. The list is by no means exhaustive. The legal mechanisms are presented chronologically to simplify analysis and to conform with the other chapters.

Comments

One goal of a Strategic Environmental Assessment (SEA) system is "to obviate the needless reassessment of issues and impacts at project level where such issues could be more effectively be dealt with a strategic level, and offer time and cost savings."[5] In that light, the various environmental assessment tools described above (strategic, sectoral, cross-sectoral and regional) enable the least desirable options for a project to be ruled out at an early stage[6] before too much time and money has been invested in the project.[7]

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4 Jean-Marc Lavieille believes that international environmental law can influence and inspire national law because States usually try to avoid all incompatibilities between their national law and the international law while adopting new regulations. Jean-Marc LAVIEILLE, (1998) *Droit international de l'environnement*, collection Le droit en questions, Paris, Éditions marketing S.A., p. 12.

5 Riki THERIVEL, Elizabeth WILSON, Stewart THOMPSON, Donna HEALEY and David PRITCHARD (1992), *Strategic Environmental Assessment*, Earthscan Publications Ltd., London., p. 35.

6 In Nepal, this process gave foreign investors a list of seven sites and potential projects among 77 possibilities that had been selected in the country as the most desirable socially, economically and environmentally.

7 Three major benefits of SEA were identified by the Ministry of Housing, Spatial Planning and the Environment of the Netherlands. First, SEA strengthens project-level EA. Second, it addresses cumulative and large-scale effects. Finally, it incorporates sustainability considerations into decision making. (See Subtask IV.)

In Hungary, "over the past few years protest movements have interrupted the construction of a hydropower project on the Danube River, prevented the founding of a storage facility for low and medium level nuclear waste, enforced the re-routing of a high-voltage transmission line, etc. Decisions on the type and location of future power stations have become particularly difficult, because every option is opposed strongly, either by green movements or by local representatives. Because none of the political parties in Hungary has yet formed a definite policy on these questions, governmental decisions had to be postponed." G. VAJDA, "Environmental Impact of Electricity in Hungary" in International Atomic Energy Agency, *Electricity and the Environment, Proceedings of the Senior Expert Symposium*, Helsinki, May 13 to 17, 1991.

6.3.1
Policy Level

Table 22: ***Legal Instruments Associated with the Policy Level***

Legal Instruments	Examples	Concrete Objectives of Legal Instruments	Corresponding Ethical Principles
Strategic environmental assessment – Public consultation to determine policy orientations and goal.	• Energy policy (Nepal)[8] • Ministry of Housing, Spatial planning and the Environment (Netherlands) • Energy policy deriving from the Consultation Table on Energy (Québec and Canada).	Ensure public involvement in determining policy orientations.	Participatory decision-making
Sectoral environmental assessment.	• Master planning and Protection Plans for watercourses (Norway)	Define orientations such as types of energy production to be prioritized.	Optimality
Cross-sectoral environmental assessment defining the orientations on which there is a broad consensus.		An EA should define the orientations on which intervening parties agree in principle and ensure that when a site-specific environmental assessment is conducted, the choices and orientations made in the EA are not reconsidered. Examine alternatives and give priority to energy sources respecting sustainable development, such as hydropower. Co-ordinate with other plans (river basin management, water management plan, agricultural plan, etc.).	Optimality Stewardship
Regional environmental assessment		Provide a local framework that can avoid much of the work done at the project-specific EAs.	Optimality

8 SEA Drafting group, Nepal Power Sector, Sectoral Environmental Assessment, revised February 28, 1997.

The SEA allows institutions to consider such criteria as developed river basins; recognized and protected natural and human sites; habitats of high quality; flooded areas; the introduction of exotic species; rare, threatened and endangered species and habitats; endemic and migratory species and habitats; species of commercial or subsistence use; displaced populations; useful reservoir life; and downstream flow modifications.[9] Such criteria, which deal with more general issues, help to screen options early in the process (see Chapter 7 – *Summary and Recommendations*).

Applying SEA to public policies might improve the EA and/or licensing processes, in particular if it arbitrates the most fundamental interests of various stakeholders (the proponent, citizens, and government) early in the process. It would help ensure that energy choices are made to the benefit of society as a whole and that they take into account all development concerns, the environment and the rights of the people.

As recommended by other authors, the public should be part of the SEA process. It would seem useful to involve the public in discussions on the environmental impact of public policies, even if a SEA can be carried out without the benefit of public inputs.

To allow legitimacy and fairness into the decision-making process, public participation should be an integral part of SEA. Public participation allows governments to make informed policy choices about energy production and ensures that citizens are aware and influence the choices made. The proponent of a hydropower project (for example on a river basin accepted at the policy level) should then have an understanding and a certain assurance that hydropower development is possible in principle.

In a democracy, an elected government is entrusted with arbitrating all public policy concerns and with addressing some fundamental ethical dilemmas such as those raised by energy development. Public authorities should therefore formulate political energy policies and ideally incorporate some sort of SEA process to their policy planning. Such a process can prevent energy policies from being reconsidered when the detailed impacts of a project are being assessed. For reasons of efficiency and optimal decision-making, it is desirable that a clear distinction be made between debates about a country's energy policy which should be included in a SEA, and debates about the merits of a specific project, which should be included in the environmental assessment of that project. Once orientations are determined at the policy level, they should not have to be reconsidered every time a project is proposed. Then, at the project EA and/or licensing stage, review panels should focus on matters related to the specific environmental acceptability of the project, the selection of the best project option, impact avoidance through design optimization, impact mitigation and compensation, as well as environmental monitoring.

We have reviewed in greater detail two specific cases: the sectoral environmental assessment of the Nepal power sector and master planning in Norway.

In Nepal, a sectoral environmental assessment was conducted on the energy sector. The assessment first considered alternative generation options and future prospects. It then drew up an inventory of 138 potential hydro projects. This inventory was coarse-screened to 44 projects. Field inspectors, fine screening and ranking then further reduced the number of projects in the selection process. This resulted in 24 projects with a high possibility of success during the feasibility stage. After fine ranking and on the basis of the technical-economic and environmental-social ranking, seven of the 24 projects were selected for full feasibility and EA/SEA study. Now that this process is complete, the next step will be to prepare project-specific EAs, which must meet the previously adopted Nepal standards.

As for the Norwegian Master Plan, it identifies watercourses that require protection and are ineligible for hydropower development. Hydropower projects remain possible on all other watercourses.

9 In this light, an SEA addresses more general issues, while project-specific EAs can deal in detail with local effects. Hence, an SEA helps refocus and streamline the EA process, avoiding some of its major limitations. See Subtask IV Report.

Yet in a recent case where a hydropower project was proposed on a watercourse available for development, the master planning orientations were reconsidered. This example illustrates the difficulties which may be encountered in complying with the recommendations of an SEA. If a project becomes the subject of a national debate, decision-makers may not feel constrained by the decisions made previously in an SEA, especially if a master plan is several years old or was approved by a different government.

One important conclusion to be drawn here is that legal mechanisms are not enough to allow choices to be made. Elected officials should make decisions to help resolve ethical dilemmas at the SEA stage and adopt other appropriate legal mechanisms for subsequent project planning and implementation stages as described in the following subsections.

The EA process required for a specific project following a general SEA should, for reasons of predictability, be as streamlined as possible. In theory, once the justification and comparison of alternative project options has been dealt with at the SEA level, alternative power generation options need not be addressed at the EA and/or licensing stage.

6.3.2
Project Planning Stage

Legal Instruments Associated with Planning

Hydropower planning often involves a series of stops and starts, since it depends upon:

- Management factors such as changes in investors, engineering consultants and project contractors.
- Financial factors such as changes in macro and micro economic conditions.
- Political factors such as changes in a country's energy policy, changes in government, local conditions, shifts in public opinion, and changes in the relations between neighbouring states.

The legal mechanisms presented below are associated mainly with the last part of planning (the licensing process) but this may differ from one jurisdiction to another. Prior to licensing, the proponent is usually responsible for conducting studies that are deemed appropriate.

Table 23: ***Detailed Description of a Project***

Legal Instruments	Examples	Concrete Objectives of Legal Instruments	Corresponding Ethical Principles
Detailed description of the project submitted to government authorities, as well as justification for the project and the consequences if the project is not undertaken.	• Presentation of report for a proposed project to the environmental authority (Spain) • Project notice to the federal authority (Canada) • Project notice to the Ministry of the Environment (Québec)	Determine the extent of the project itself and a description of the necessary accessory projects if required.	Optimality Stewardship

In some jurisdictions, it is mandatory to describe in detail all necessary infrastructure projects related to the main project, such as power lines, quarries and access roads (related undertakings), to ensure that the overall environmental impacts associated with the project are examined. Sometimes a project notice or EA may be rejected because some related undertakings have not been included. Hence, if the levels of detail required in a description of the project are unclear, a lack of predictability may result.

Table 24: ***Screening***

Legal Instruments	Examples	Concrete Objectives of Legal Instruments	Corresponding Ethical Principles
Screening methods: • Legislative thresholds above which an environmental impact assessment study is mandatory, or: • Specific exclusion list of projects. • Specific inclusion list of projects. • Comparison of the project with a list of resources, environmental problems (e.g., erosion) or areas of special sensitivity (e.g., flood plains).	• European Commission, DGXI "Guidance on screening" • *Environmental Impact Assessment Act,* 1994 (Taiwan) • *Implementing Policy for Environmental Impact Assessment and Environmental Examination on the siting of Power Plant* (Japan) • *Royal Decree 1131/1988* (Spain) • *Act of the Environment Impact Assessment Procedure,* 1994 (Finland) • *Inclusion List Regulations* (Canada); *Exclusion List Regulations* (Canada); *Comprehensive Study List Regulations* (Canada); *Law List Regulations* (Canada)	Screening requires deciding whether a project is likely to have significant environmental effects by virtue inter alia of its nature, size or location. Screening provides a designation of types and sizes of power plants for which an EA is mandatory. Preliminary activity is undertaken to classify proposals according to the level of assessment that should occur.	Optimality

Instead of improved optimality, screening may sometimes have the opposite effect. Indeed, if the thresholds are too low, then every or almost every project will require a full EA study. However, all parties benefit if time and money are saved because some predetermined types of projects with minimal impacts are exempted from a detailed EA process.

Table 25: ***Class Assessment***

Legal Instruments	Examples	Concrete Objectives of Legal Instruments	Corresponding Ethical Principles
Class assessment: development of EA content for various projects that generally have a small, predictable range of effects.	*Canadian Environmental Assessment Act*	Identify similar projects with similar environmental impacts. A single EA is thus prepared for the class, determining the extent of the project itself and a description of the necessary accessory projects, if required.	Optimality

A class assessment for projects with a predictable range of effects can increase the predictability of the EA process, thereby improving optimality. However, hydropower projects are very site-specific. Therefore, efforts should be made at least to develop processes that include references to information gathered during previous monitoring and follow-up studies of comparable projects.[10]

10 The ecosystem in the area of the proposed Grande Baleine project in Québec is very similar to that in the area of the La Grande Complex. The latter was completed over the last 20 years, and long follow-up studies on the biophysical environment were conducted. The opportunity to increase the optimality of the process by using this previous knowledge was missed, and costly duplication occurred.

Table 26: ***Terms of Reference and Scoping***

Legal Instruments	Examples	Concrete Objectives of Legal Instruments	Corresponding Ethical Principles
Scoping of EA: • Identify early significant impacts of issues • Identify alternative designs and sites • Prepare plan for public involvement • Determine the extent of impact on population • Often includes public hearings • Terms of reference detailing the contentof the EA	• European Union DGXI "Guidance on Scoping" • European Directive on EIA 85/337EC modified in 1997 by Council Directive 97/11/EC • In Italy, the DPR 27/12/1988 stipulates what an EA must include in the hydropower sector. • *Methodological Guide for the Development of Environmental Impact Assessment for Big Dams* (Spain) • Scoping guidelines, Environment Canada • Generic directive (guidelines) for EA of hydropower projects, Québec Ministry of the Environment	Decide the issues to be investigated in the EA, once it is decided that an EA is required. Identify impacts in the short and long run. Identify significant issues early in the planning process. Determine the content of the EA to be prepared.	Optimality Stewardship Participatory decision-making

Scoping is the "process by which the important issues and alternatives that should be examined in environmental impact assessment are determined." [11] Scoping helps focus the assessment on the key issues and reduces the length of the process while preventing irrelevant information from being required. It is an essential tool for developing terms of references for specific projects.

In that light, when the terms of reference (or guidelines) detail the content of the EIA, the process is more effective, since it ensures that no significant impacts will be overlooked. They should focus on relevant issues and consider results from previous follow-up studies and the knowledge acquired.

The sources of impacts of hydropower projects can be divided into four main groups: construction activities, hydro installations (works and infrastructure), reservoirs and hydrologic management. Scoping ensures that the impacts resulting from these sources are analyzed.

However, an EA on a hydropower project is usually site-specific. Although the EA addresses impacts at a given site, it does not necessarily address concerns for all alternative projects, whether they are alternative hydropower projects or alternative sources of energy production. This is true when an EA and/or licensing process is in force without a prior SEA process in place. In fact, a proponent often realizes late in the process that the project is unacceptable to citizens or authorities. This rejection may result from a comparison of hydropower projects with other types of projects, even though the environmental impacts of these other projects have not been evaluated and their life cycles have not been examined. Actually, a hydropower proponent might not be in a good position to carry on studies for other energy options.

11 William A. TILLEMAN, (1994) Dictionary of Environmental Law and Science, Toronto, Emard Montgomery Publications Limited.

Hydropower projects require major investments and a long construction period. In addition, the EA of a hydropower project examines all aspects of the life cycle. Such a complete analysis is not usually undertaken for other projects in the energy sector. For example, coal extraction, transportation and use in a coal thermal plant are generally considered three different projects. Since the different installations and activities in many thermal projects involve different proponents, these projects may have an advantage over large, comprehensive hydro projects.

Given the construction delay and investments required, it is crucial for a proponent of a hydropower project to know early on whether the project is acceptable. Indeed, the real problem with the EAs and/or licensing processes of hydropower projects might be the absence of a real EA at the policy level previously conducted.

Indeed, scoping sometimes add items to the environmental impact study rather than focus on the relevant issues.[12] In such cases, scoping addresses all stakeholders' concerns, thereby increasing costs and reducing the predictability of the process. The problem may be that, to respect participatory decision-making and ensure fairness and justice, the processes allow all concerns to be taken into account, whether or not they are significant for a future decision. As a result, the conflict between these two opposing perspectives leads sometimes to inefficient process. There is a tendency to refrain from making choices that are controversial and thus open the door to any peripheral demand.

Another key issue about the scoping stage is the division of responsibilities between the different parties involved in the process. In order to make the process more efficient, it is necessary to define the role and responsibility shared by all parties. For example, it is logical to believe that the EA program should be developed by the same authority that is later responsible for assessing the EA. Also, the exchange of information between local and central authorities must be coordinated by one responsible authority. In practice, this might not be the case.

Table 27: ***Common Assessment***

Legal Instruments	Examples	Concrete Objectives of Legal Instruments	Corresponding Ethical Principles
Mechanisms for common assessment of all levels having jurisdictions.	• *Competence of town-planning authorisation allocated to the State in the case of public interest works* (Italy) • *James Bay and Northern Québec Agreement* • *Canadian Environmental Assessment Act* (starting from section 40: common examination)	Avoid redundancy of processes.	Optimality Stewardship

12 Bob Everitt identified several problems occurring when jurisdictions have difficulty narrowing down the scoping process. For example, he notes that EA statements have become exhaustive voluminous documents with unnecessarily comprehensive data and that important issues are either not identified during the EA or identified too late. This situation wastes time and money. He also reports that many irrelevant or insignificant issues are not eliminated and therefore also waste time and money. (Bob EVERITT, *Scoping of Environmental Impact Assessment,* Paper to EA Process Strengthening Workshop, Canberra, April 4 to 7, 1995.) Barry Sadler, citing Everitt, also mentions the problematic issue of scoping. He notes that particularly when public consultations occur in the process, the range of concerns tend to open up and jurisdictions seem to encounter difficulties "closing the scoping diamond" and identifying "the impacts of real concern to be analyzed in an EIA study and report." (Barry SADLER (1996) International Studies on Efficiency and Effectiveness of Environmental Assessment: *Final Report – Environmental Assessment in a Changing World: Evaluating Practice to Improve Performance,* Ministry of Supply and Services, Ottawa, Canada, p.113.)

In countries where various levels of government have jurisdiction over environmental assessment, more than one set of public hearings may be scheduled and more than one EA prepared. Sometimes the process may become exceedingly complicated with an overlap of several procedures.[13] For that reason, some mechanisms are adopted to allow for a common assessment by all levels of jurisdiction. Indeed, such common assessment procedures should be mandatory to avoid redundancies in the EA and/or licensing processes and incompatible decisions. Process redundancies have led to different conclusions on whether to authorize projects. Common assessment allows all considerations to be taken into account in a single step, thereby increasing optimality.

For true efficiency in federal states, for example, the division of powers should be clearer and duplications avoided. Policies avoiding duplications should be promoted. Otherwise, stakeholders pay the price for the poor division of work and for the confusion resulting from the different processes.

Table 28: ***Public Participation and Public Hearing***

Legal Instruments	Examples	Concrete Objectives of Legal Instruments	Corresponding Ethical Principles
Procedures for public consultations during the conception stage.	• Ontario guidelines on pre-submission consultation in the EA process.	Involve the public as soon as possible in the planning process.	Participatory decision-making
Public hearings, continuous access to information, etc. prior to authorization of the project. Public registry of the information filed by proponent and of EIA.	• *Paper announcement of the proposed project and public meetings in the affected area* (Norway) • *Environment Quality Act* (Québec) • *Canadian Environmental Assessment Act* (Canada)	Encourage public involvement.	Participatory decision-making Fairness and justice
Independent review panel. EA is conducted by an organization other than the proponent. Public hearings and/or receipt of comments by public, groups, etc.	• *National Environmental Impact Assessment Guidelines* (Nepal) • *Environmental Impact Assessment Act* (Korea) • *Canadian Environmental Assessment Act* (independent panel) • *Environment Quality Act* (BAPE, outside of government, making recommendations)	Avoid conflicts of interest.	Fairness and justice Participatory decision-making
Process of consensual conflict resolution for conflicting uses of ressources such as management of water basin.	• *Environmental Quality Act* (access to information) • *Access to Information Act* (Québec)	Opportunity to be involved at the operational phase. Access to information for the public after authorization.	Fairness and justice Participatory decision-making

13 In Québec, the Grande Baleine project had to fulfil five EA and/or licensing processes: three at the federal level and two at the provincial level. The proponent was responsible to bring the parties together and having the authorities sign a memorandum of understanding aimed at co-ordinating the five processes.

Public participation

Public participation is useful to the decision-making process of public authorities. As stated before, as an ethical principle, the Rio Declaration clearly states – under Principle 10 – that public participation must be facilitated for all environmental issues. Funding for interest groups is one frequently considered mechanism to ensure real public involvement. One way to encourage public involvement is to ensure public hearings while offering continuous access to the information, namely through a public registry. Citizens should be able to obtain the information filed by the proponent and consult the EIA produced.[14]

Public hearing process

The commissioners conducting public hearings are faced with a heavy and complex task. Stakeholders in a debate must be treated according to clear rules which allow for arguments and counter-arguments to be exposed and debated openly. The procedures should allow any stakeholder, including project proponents, people opposed to the project, government representatives and the general public, to be challenged in their arguments, in order for the population to gain an informed opinion. Consequently, responsible institutions should adopt a code of basic procedural rights for public meetings or hearings in order to ensure that all actors are treated fairly and that their roles are clearly defined.

Table 29: ***Mandatory Deadlines/Time Frame of the Process***

Legal Instruments	Examples	Concrete Objectives of Legal Instruments	Corresponding Ethical Principles
Mandatory deadlines for steps in the process and/or for the total duration of the process Clear rules applicable to the process Conditions of approval set by government authorities	• *Act on the Environmental Impact Assessment procedure* (Finland) • Royal Decrees 1302/1986 and 1131/1988 (Spain) • *Environment Quality Act* (public hearing procedure); *Regulation on the Evaluation of Environmental Impacts* (section 16.1: 15 months for major industrial projects); *Rules of procedures applicable to the public hearing process; Environment Quality Act* (section 31.7: the government decision binds the Minister) (Québec)	Predictable process, including time frame of the process, rules applicable to the process and goals of the process.	Optimality

Mandatory deadlines for the EA and/or licensing stages, including deadlines for the total duration of the process help improve predictability and hence optimality. In practice, however, only a few mandatory deadlines are enforced. As a result, authorities can make discretionary decisions on what is considered an acceptable time-frame for a final decision to be rendered. In the case of large hydropower projects, this can have adverse consequences. Given the extent of investments and of time required to complete a hydropower project, decisions should be made with diligence and the duration of the entire licensing process be clearly established beforehand.

14 This need is particularly felt in developing countries. For example, it has been said that the Federal Environmental Protection Agency (FEPA) of Nigeria should produce more guidelines and circulars to increase public involvement. Also, copies of approved and rejected final EIAs and screening reports should be made available at all FEPA zonal offices throughout the country. (Femi OLOKESUSI, (1998) “Legal and Institutional Framework of Environmental Impact Assessment in Nigeria: An Initial Assessment,” *Environmental Impact Assessment Review,* 159, 173.)

Table 30: ***Inter-Agency Committee***

Legal Instruments	Examples	Concrete Objectives of Legal Instruments	Corresponding Ethical Principles
Inter-agency committee in some jurisdictions coordinate the intervenors (within and outside government) from different sectors.	• A liaison conference involving local governments and ministries concerned prior to approval of EA (Japan) • Regulations respecting the co-ordination by federal authorities of environmental assessment procedures and requirements (co-ordination between the federal authorities) (Canada)	Co-ordination of intervenors from different sectors.	Optimality

In some countries, efforts are made to ensure that effective co-ordination exists among the intervenors within and outside government. At the very least, ensuring that effective co-ordination processes exist among government agencies can help reduce potential redundancies in EA and/or licensing processes. Effective co-ordination processes with non-governmental stakeholders also improve optimality and should therefore be promoted.

Table 31: ***Approval of the EA by Government Authorities***

Legal Instruments	Examples	Concrete Objectives of Legal Instruments	Corresponding Ethical Principles
EA approved by competent government body.	• Official announcement on basic plan of electric power development (Japan) • Compliance notice from the Ministry of the environment; Authorization certificate from the Ministry of the Environment (Québec) • Federal authorizations (Canada)	Once a compliance notice is received for the EA, the proponent knows that government authorities are satisfied with the content of the EA, the extent and nature of the study, etc. Ministry or government authorization of projects (as elected officials representing citizens, therefore being "entrusted" with the duty) including conditions and mitigation measures initially and at fixed periods or when the project is modified.	Stewardship Prudence and control

Government authorities, according to some legal processes, send a compliance notice or some other form of EA approval to the proponent. This notice states whether government authorities are satisfied with the content of the EA, with the extent and nature of the study, and with the proponent's compliance with the guidelines. The notice provides for optimality and should be encouraged. In addition, it may be relevant to formalize approval of the EA and its compliance with the guidelines to prevent its content from being reconsidered later during the process.

Table 32: ***Authorization of Project by Government Authorities***

Legal Instruments	Examples	Concrete Objectives of Legal Instruments	Corresponding Ethical Principles
Access to information for the public. Publication of decision. Mechanisms for the public to appeal or contest an authorization granted to a proponent.	• This type of process is more readily available in the United States • Publication of decree in the Gazette; Authorization certificate accessible on demand (*Access to Information Act*) (Canada)	Transparency of the authorization process.	Fairness and justice

When government authorities authorize projects as elected officials, they represent citizens. They are therefore entrusted with arbitrating and making political choices for the people, while taking into account such needs as energy, fresh water supply and environmental protection. Governments have the option of including conditions and mitigation measures initially at the project and construction stages and also at fixed periods or when the project is modified.

Some concerns have been expressed about monitoring and follow-up studies. These studies could be more credible if undertaken by independent parties rather than by the proponent. However, if government authorities verify or ensure that proponents duly implement required environmental mitigation programs, such mechanisms can help increase stewardship.

Prudence and Control in Decision-making

Prudence and control are recognized as basic principles of responsible environmental management and should be integrated into the decision-making process. However, prudence and control should not be used as arguments to halt all development projects. Some project might avoid substantial environmental harm, such as reduced pollutant or greenhouse gas emissions. In environmental matters, prudence and control applies to global environmental threats as well as to local ones.

The precautionary principle aims to prevent a lack of full scientific certainty from being used as a reason to postpone cost-effective measures to prevent environmental degradation, when serious or irreversible damage is possible. This principle ensures that potential environmental harm is considered even when scientific evidence is not fully available.

6.3.3 Implementation Stage

Table 33: ***Legal Instruments Associated with Implementation***

Legal Instruments	Examples	Concrete Objectives of Legal Instruments	Ethical Principle Implementation by Legal Instruments
Conditions and mitigation measures imposed in a license	• Conditions for an authorization certificate (Québec) • Some licenses given with a 5 year test period (Norway) • Mitigation measures fixed by the Water court during the application process (Sweden)	Modify the design or other aspects of the project to mitigate impacts. Optimize the mitigation measures.	Control Stewardship
Expropriation procedures Compensation to populations such as aboriginal people	• *James Bay and Northern Québec Agreement ; Québec Expropriation Act* (Québec)	Compensate those affected fairly. Ensure that benefits from the project will exist for generations to come. Fair decisions on compensation are possible with public participation, affected population, groups, etc. Fairness is also linked to transparency. It is as important for the process to seem fair for all affected interests as it is for the process to be fair.	Fairness and justice Participatory decision-making
Compliance with the legislative and regulatory framework of the country where the project is undertaken Compliance with all applicable legal standards and other standards in a proactive manner		An environmental management system helps go beyond simple compliance and can control all risks associated with a project.	Prudence and control Stewardship
Periodic audits of approvals Site inspections Possibility of revoking the authorization certificate if conditions are violated. In certain jurisdictions, relicensing is required at fixed periods	• *Environment Quality Act* • Authorization certificate from the Québec Minister of the Environment	Verify compliance. Have inspectors monitor (after and during construction and operation). Give operators environmental training. Use mitigation measures.	Prudence and control Stewardship

Comments

In the case of the ISO 14001 standard, an environmental management system (EMS) is defined as "the part of the overall management system that includes [the elements needed to] develop, implement, achieve [the goals of], review and maintain the environmental policy [of the organization]".

Concerning legal requirements, a hydropower plant operator which implements an EMS such as ISO 14001 must demonstrate that procedures have been established and are maintained to identify, and have access to, the legal requirements that apply to the environmental aspects of its activities. Furthermore, a certification/registration process is carried out by a third party independent organization. This process attests that the plant operator is committed to legal compliance (in its environmental policy) and that the activities required to be in compliance have been carried out.

The ISO 14001 standard, for example, includes other requirements – environmental aspects, goals and targets, management programs, training, EMS auditing, management review, etc. – that altogether allow an organization to react with "due diligence" and proactively to all environmental risks, even those that are not referred to in the legal requirements.

In fact, even though the only "performance" requirement in the ISO 14001 standard is to respect laws and regulations, the general goal of the EMS is to achieve continual improvement, and in the end, go beyond legal compliance.

6.3.4 Operation Stage

Table 34: ***Legal Instruments Associated with Operations***

Legal Instruments	Examples	Concrete Objectives of Legal Instruments	Ethical Principle Implementation by Legal Instruments
Mandatory follow-up by proponent and mandatory transmission of information to government authorities.	• *Canadian Environmental Assessment Act* (Canada) • Authorization certificate issued under the *Environment Quality Act* (Québec)	Ensure compliance at the operation stage	Prudence and control Stewardship
Revision of license terms and rules of operation. Compliance with the legislative and regulatory framework of the country where the project is undertaken. Compliance with all applicable legal standards and other standards in a proactive manner.	• Possibility of license revision initiation by local population and public after 30 years of operation (Norway)	Ensure compliance and amelioration at the operation stage Implement an environmental management system in conformity with the ISO 14001 standard and obtain formal certification. Over time, an environmental management system reaches beyond simple compliance and can better control all risks associated with a project.	Prudence and control Stewardship

Comments

Environmental follow-up is a necessary and important exercise. Unfortunately, the information and knowledge obtained through follow-up are not always used in designing guidelines for subsequent EAs for similar projects. It should be required that this information be used in other projects. Otherwise, important data are lost and society must bear additional costs to redo studies on topics for which data already exist.

Environmental protection is improved and stewardship is increased when a project complies with all applicable legal standards and when an operator is proactive by respecting voluntary standards as well as mandatory ones. Government authorities must verify compliance. By being proactive, a proponent may both increase its credibility and ensure better environmental protection.

As described in 6.3.3, an EMS promotes continual improvement and should help an organization to reach beyond simple compliance.

Furthermore, taking example on other international standardization efforts like Sustainable Forestry Management (SFM – see ISO/TR 14061:1998), it could be possible for an organization like the ISO or the IEC to undertake the task of putting together, in a technical report, the principles by which dams and reservoirs should be "environmentally" managed and operated. These principles could then be interpreted as "other requirements" within the ISO 14001 framework, in as much as each operator adheres to them. The SFM has the merit of being usable everywhere in the world, because it makes room for regional variations.

Another example in this field is the " Responsible Care " program, used by many in the chemical, oil-and-gas and paper industries. Mainly by way of Codes of Practices and stringent auditing techniques, the RC program puts forth more environmental performance requirements than either ISO 14001 or SFM. On the other hand, though, the RC program was designed by an industrial association, and applying it is a prerequisite to be a member of the industrial association.

6.3.5 Upgrading, Relicensing and Decommissioning Stages

Table 35: ***Legal Instruments Associated with Upgrading, Relicensing and Decommissioning***

Legal Instruments	Examples	Concrete Objectives of Legal Instruments	Corresponding Ethical Principles
Authorization of upgrading activities (restoration, refurbishment, enlarging, etc.)	• Study of environmental integration into the landscape required while upgrading (Italy) • EA required for major project upgrading (Finland) • Authorization certificate, Environment Canada (Canada)	Ensure compliance of additional activities.	Prudence and control Stewardship
Relicensing of the whole project at fixed periods for private installations.	*Federal Water Power and Federal Energy Regulatory Commission Regulation* (United States).	Ensure compliance at fixed periods.	Prudence and control Stewardship

Comments

By requesting that upgrading activities[15] be authorized once completed or at fixed periods (relicensing[16]), government authorities reconsider environmental impacts and work towards stewardship. They monitor these activities and ensure that mitigation measures are in place to minimize environmental impacts.

The relicensing procedure in the case of multiple usage projects is used as a negotiation process between multiple stakeholders. The debate about how much water is allocated for each usage, is arbitrated by a public body (e.g., the Federal Energy Regulatory Commission in the United States) after a set of environmental and social studies, as well as public hearings.

In jurisdictions without a relicensing procedure, authorizations are not granted for a limited period. The rationale is that almost the entire hydroelectric life cycle is thoroughly analyzed at the construction phase. In these jurisdictions, the goal of relicensing (to ensure that environmental impacts are still acceptable after several decades of operation) is nevertheless achieved by subjecting major upgrading and enlargement activities to an EA and/or licensing processes. Whenever major impacts occur changes to operations and equipment generally require a new EA.

In some jurisdictions, if the conditions of an authorization are violated or if a proponent breaks the law, the government may withdraw the authorization and require another complete EA before the project can resume operation.

6.4 CONCLUSIONS

6.4.1 General Remarks

Environmental assessment (EA) is both a management tool and an indispensable aid for decision-making. Its purpose is to help elected officials and project proponents make well-founded decisions, to give clearance or not to a project once its environmental impacts are fully assessed, and to improve the project design itself. EA is not an aim in itself, but an instrument used by stakeholders to fulfill their duties, in accordance with relevant legal and regulatory frameworks.

Since the seventies, most countries have created legal and regulatory frameworks to protect their environment, among which environmental approvals and licensing processes. They have used these tools to ensure that large infrastructure projects do not cause unacceptable adverse environmental impacts. The appropriateness or importance of such tools is not questioned here. Rather, it is our belief that we have learned from past experiences and that we can draw certain conclusions to improve on past practices.

In light of our analysis on the effectiveness and efficiency of regulatory processes as applied to hydropower projects, there is growing concern that environmental approvals and licensing processes have become overly rigid and cumbersome in many OECD member countries. In certain cases, such processes impose costs on society and project proponents that are not commensurate with the benefits gained or impacts avoided. Such costs may include, among others, excessive and unreasonable information requests, unnecessary operational restrictions and unreasonable delays to project implementation schedules. Such costs may even lead to the cancellation of beneficial projects. The lack of balance sometimes observed in the EA and licensing processes can be linked to one or several of the following concerns:

- Process driven reviews instead of issues or priorities driven reviews.
- Insufficient consideration given to the potential trade-offs associated with the benefits provided by a proposed project.
- Uncertainties brought about by conditional approvals given to proponent's requests.

15 Upgrading activities include capacity restoration, renewal, rehabilitation, refurbishment, uprating, enlarging and redevelopment. They do not include maintenance activities or the building of new projects.

16 For countries where licensing is required and granted for a limited time, relicensing refers to the renewal and/or extension of the licence (permit for the industrial use of water) once the licence period has expired. In the United States, relicensing applies to privately-owned facilities.

- Duplication of requirements due to the lack of coordination between and within regulatory agencies.

- Lack of technical basis for evaluating project impacts.

- Aversion to decision-making by concerned regulatory agencies.

Around the world, the demand for reliable power supplies is steadily increasing. Electricity prices have recently been following upward trends in a number of countries. In part, this reflects insufficient new investments in power generation for a number of years. Because hydropower projects are more affected by uncertainty, including market and regulatory uncertainty, there are fewer new hydropower projects being developed throughout the world. This is regretful in view of the fact that many countries still have abundant hydroelectric resources to develop, combined with increasing needs.

Unduly refraining hydropower development is not desirable because hydropower may, in many cases, be more environmentally benign than other traditional sources of power. Nonetheless, policy errors are still being made when allocating power generation resources. Investments in power generation currently being planned are, in many parts of the world, mostly thermal electric, which produces greenhouse gases and other air, water and land pollution. Hence, by discouraging investment in hydropower projects, decision makers may inadvertently encourage power generation investments that might be more damaging to the environment than hydropower.

Regulatory reform is required to address certain imbalances and to avoid a poor allocation of resources for power generation. Project proponents, along with governments and non-governmental organizations, share responsibilities with regards to the development and implementation of legal and regulatory frameworks governing hydropower development, including environmental assessment and licensing processes. In our summary and recommendations, we discuss how these various stakeholders could contribute to improve these aspects.

6.4.2 Governments

The existing environmental approval and licensing frameworks put a strong emphasis on the environmental assessment process. That been said, it is increasingly clear that EA is not a cure for all problems. Indeed, the current EA process has frequently encountered major difficulties in terms of efficiency and predictability for hydropower projects. Other complementary measures and legal instruments should therefore be designed to overcome and solve such problems. Because of the costs and uncertainties involved in the lengthy planning and licensing processes associated with hydropower development, such measures should include approval processes which are effective before undertaking time-consuming and costly site-specific EAs.

Our study has shown that some countries have adopted environmental assessment mechanisms at the policy-making level that precede and complement site-specific EAs. Although the results of such mechanisms are still mixed in many cases, it appears that these instruments are by nature much better tailored to integrate certain sensitive aspects related to hydropower development, such as the rights of local, regional and national populations and minorities to participate fully in the decision-making process.

Without appropriate policy-making mechanisms to ensure clear policy guidance from public decision-makers, hydropower project proponents end up shouldering several duties that should not come entirely under their responsibility. Regretfully, it appears that EAs at the policy level are still too embryonic to offer the adequate forum required by those who have specific rights to assert at the project-planning stage (land claims, policy debates, etc.). It also appears that the traditional site-specific EA process for hydropower projects has become overly rigid and cumbersome, and thereby somewhat ineffective and inefficient with respect to the purposes it serves.

6.4.3 Non-Governmental Organizations

In some countries, problems still arise when the compulsory legal framework with regards to EA processes is not in place or when the appropriate legal and institutional frameworks have not yet fully come into force. These problems become even more acute when the required human and technical resources are lacking.

The case of emerging economies raises specific development questions. These questions touch particularly upon issues associated with human rights or the third generation of rights; these refer to complex new notions of rights associated to ethical issues (see Volume III, Appendix I). The procedures adopted by developed countries for site-specific projects cannot by themselves effectively reconcile the interests and expectations of intervening parties. The need for such reconciliation is even more critical for emerging economies given that people's basic needs are more often directly affected by a project.[17] Since this is a very complex matter, these issues cannot be discussed in-depth in the present paper.

However, it is important to mention that non-governmental organizations (NGOs) can play an important role in helping to fill the holes left by the absence of a compulsory legal framework with regards to EA processes. For instance, in countries where national legal and regulatory frameworks for EA do not exist or provide inadequate protection in such matters, NGOs can provide assistance for the implementation of the EA processes required for their own projects. The implementation of such processes is crucial in countries where human rights and development issues are strongly affected by large infrastructure projects.

6.4.4 Proponents

As previously stated, project proponents also share certain responsibilities when it comes to the design and implementation of the legal and regulatory framework for EA.

In general, EA processes focus more on potential adverse impacts and required remedial measures than on providing a balanced analysis of potential adverse impacts and potential benefits. Are we too negative? Some authors have raised this question specifically in the case of developing countries. In *Environmental Impact Assessment for Developing Countries,* authors Thanh and Tam mention: "It is high time we asked ourselves if we have made a fair evaluation between improvement of poverty and backwardness on the one hand and the protection of our environment on the other."

It is our belief that within the EA process, the potential adverse impacts of a project should be weighed against its potential benefits. The key question to be addressed is: What long-term benefits (agronomy, industry, etc.) are likely to result from the project to offset its long-term environmental impacts? The overall impacts and benefits of a project should be considered as a whole. They should not be limited to the present and near future conditions of the directly affected area,[18] of a specific economic sector,[19] or of a segment of the population.[20] Of course, this requires delicate trade-offs and is a very complex task. It might be even more complex in economically emerging countries since intervening parties are not always well represented.

Project proponents should act in accordance with fundamental ethical principles when local institutional capacities are insufficiently adapted to the requirements of the EA process. It is our view that proponents should adopt a code of conduct to ensure that EAs are adequately conducted and human rights respected throughout the power industry, particularly in regions where minimum standards are non-existent or inadequately enforced. Such a code should provide adequate guidance for environmental management, public participation and conflict resolution at each step of project development. It should apply to all stages of project planning and implementation.

Finally, environmental management systems such as the ISO 14001 standard is interesting to consider in the context of proponents' responsibilities. It is an internationally recognized environmental management standard which aims at ensuring continuous improvements in environmental performance. It is our view that hydropower plant operators should select an environmental management system which could be certified or registered by international organizations.

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17 Merle SOWMAN, Richard FUGGLES and Guy PRESTON, (1995) "A Review of the Evolution of Environmental Evaluation Procedures in South Africa" in 15 *Environmental Impact Assessment Review,* 45, p. 53.

18 N. C. THANH and D.M. TAM, (1992) "Environmental Protection and Development : how to achieve a balance?" in *Environmental Impact Assessment for Developing Countries* by Asit K. Biswas and S.B.C. Agarwala (ed), Butterworth-Heinemann Ltd, Oxford, p. 8.

19 Id, p. 12.

20 SOWMAN, Merle, Richard FUGGLES and Guy PRESTON, *loc cit,* note 17.

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7 SUMMARY AND RECOMMENDATIONS

7.1 INTRODUCTION

This chapter summarises the findings of Annex III work, and presents recommendations on improving environmental practices for existing and future hydropower plants.

These recommendations focus on *best practices* rather than *minimum practices*, and as such set high standards of environmental management. The practices recommended are based on a critical review of past experience by environmental practitioners who work in assessing and managing the environmental impacts of hydropower[1].

Given the site and project-specific nature of hydropower project impacts[2], not all of these recommendations apply to all types of hydropower projects: for example, a run-of-river project is not concerned by recommendations regarding reservoir management.

The review of best practices in the hydropower sector reveals that hydropower projects can be truly sustainable when they "internalise" (or fully account for) their social and environmental costs. This is a significant challenge in an era of competitive electricity markets: if other competing power generation options – coal, oil, gas, etc. – do not in turn "internalise" their own impacts, then there is no level playing field. In such a case, imposing extensive environmental requirements *on hydropower only* is equivalent to subsidising air pollution and greenhouse gas emissions. Indeed, this gives a competitive advantage to other options, which are, today, mostly thermal generators. Environmental responsibilities must apply evenly to all players in the power sector.

Public pressures and expectations regarding the environmental and social performance of hydropower tend to increase over time. Throughout the world, several projects have recently been the subject of disputes and sharp resistance. This has led in certain cases to the cancellation of major hydropower projects.

It is clear that poorly designed and managed projects are likely to have adverse consequences on local communities and the environment and to adversely affect the reputation of concerned governments, financing agencies and the hydropower industry as a whole. In short, it is in the common interest to ensure that the necessary means are taken to design, build and operate the best projects. In view of the above, what are the conditions to be met or the guidelines to be followed in order to design a good hydroelectric project? What constitutes an acceptable project from an environmental and social standpoint?

The reader should keep in mind that this report is on hydropower per se, excluding the impacts of other possible dam uses such as irrigation, flood control or water supply. This is important in view of the fact that a relatively small proportion of large dams throughout the world (20%) are used for the production of electricity, while a much larger proportion of dams (48%) are built for irrigation purposes only[3]. The proportion of dams used for the production of electricity throughout the world is even lower if one includes smaller dams: out of the 75,000 dams over 6 ft (1.83 metres) tall in the U.S.A., only 2.9% are for hydroelectricity[4].

1 See IEA Hydropower Agreement. Annex III. Subtask III/1: *Hydropower and the Environment: Survey on Environmental Impacts of Hydropower and Mitigation Measures.*

2 See IEA Hydropower Agreement. Annex III. Subtask III/6: *Hydropower and the Environment: Effectiveness of Mitigation Measures.*

3 Lecornu, J. 1998. *"Dams and Water Management"*. Conférence Internationale Eau et Développement Durable, Paris. (http://genepi.louis-jean.com/cigb/article-barrages-an.html).

4 U.S. Army Corps of Engineers. *National Inventory of Dams.* Quoted in: *Dam Removal Success Stories.* 1999. p. ix. By American Rivers, Friends of the Earth, & Trout Unlimited.

Moreover, the specific impacts of irrigation dams are frequently quite different from those of hydropower dams[5]. Unlike irrigation, hydroelectricity is a non-consumptive use of available water resources: there is no loss of water as it runs through a hydropower plant.

Because of the focus of the report on hydropower and the environment, wider issues associated with multi-purpose water resource management and the resolution of water use conflicts have not been addressed as such[6].

The present report is written from the perspective of hydropower professionals and practitioners from a selection of OECD countries. Because of the nature of the experience of the contributors to the report, the impacts of large plants have been emphasised to a greater degree than those of smaller hydropower plants.

The next section provides a summary of lessons learned.

7.2 LESSONS LEARNED

7.2.1 Recent Trends in Hydropower Development[7]

The main trends identified for large hydropower projects are:

- full integration of environmental assessment (EA) into the hydropower planning process
- the recognised need for transparency over project costs, dam safety and environmental and social impacts
- increased public interest and scrutiny of large dam projects
- increased public consultation in identifying and screening projects
- growing recognition that hydropower may be a major instrument in the fight against climate change
- developing hydropower within the context of integrated water resource planning
- increased awareness that environmental sustainability and high discount rates are in conflict
- increased private sector financing and, as a consequence, increased emphasis on cutting costs and duration of design and construction, and on reducing financial risks
- increasing difficulty for hydropower to compete against thermal generation in countries with abundant coal and gas supplies
- an increased awareness and understanding of complex technical, environmental and social issues which are inherent to large dam projects; and the realisation that the development of large dam projects requires trade-offs between potential benefits and potential losses
- a holistic approach with increased application of multi-criteria ranking models and quantification of secondary and external costs and benefits to select the most attractive hydropower projects and alternatives
- a number of technological developments which make the planning and construction of large dam projects more efficient
- increased need for safety inspection and environmental management of existing dam projects
- increased interest in modernisation and upgrading of existing hydropower schemes.

5 Goodland, Robert. 1999. *"What Factors Dictate the Future Role of Hydro in the Power Sector Mix? Environmental Sustainability in Hydro Projects."* Presented to Annex III, Madrid Technical Seminar. Hydropower and the Environment. Euroforum, Madrid March 15-17, 1999. 24p. + annexes.

6 The World Commission on Dams (www.dams.org) is reviewing the development effectiveness of large dams in general, integrating the multiple uses of dams in its studies.

7 For a full discussion of this issue, see Ch.2: *"Trends in Hydropower Development"*.

These trends occur in a context of global restructuring of the electricity sector, with increased competition between electricity producers. The privatisation of certain state monopolies in the power sector has led to the creation of new multinational corporations operating in many energy sectors. This new competitive context for electricity production will certainly favour power generation options which minimise both capital investment and the time required to bring production online. The environmental consequences of such a shift towards market-based power generation will depend on what power source the new electricity production options will displace.

Electricity restructuring poses considerable challenges to the environmental regulatory agencies, as well as to operators seeking prudent environmental stewardship: in some regions of the world, electricity markets may favour "cleaner" generation options when compared to existing power generation "mixes", but in other areas of the world, markets may favour more polluting (and less costly) options. In addition, the implementation of energy efficiency programs or of technology development programs in the power sector might require government support to compensate for the inadequacies of existing market mechanisms.

7.2.2 Comparative Environmental Analysis of Power Generation Options [8]

There is a pressing need to compare the relative environmental costs and benefits of the various sources of power generation. Indeed, the demand for power continues to increase worldwide and, in turn, the power industry continues to generate significant ecological and social impacts throughout the world. For a discussion of the comparative generic impacts associated with major power generation options (including hydropower), the reader may refer to Chapter 3 of this report.

Most major human endeavours cause environmental and social impacts, and power generation projects are no exception. However, unlike many other economic activities, power can be produced from a variety of primary energy sources and conversion technologies. Electricity may be generated from the following sources:

Thermal processes based on:

- the combustion of fossil fuels such as coal, oil or natural gas
- the combustion of biomass: peat, wood, waste and biogas
- fission reactions in nuclear power plants.

Renewable processes, such as:

- wind, using wind turbines
- flowing water, with hydropower plants
- sunlight, with photovoltaic (PV) panels
- ocean tides, and tidal power plants
- steam, originating from geothermal emissions.

Chemical processes such as:

- electric batteries, used in cars or portable appliances
- fuel cells, which transform without combustion streams of oxygen and hydrogen into electricity[9]. These are used in space stations and are under development for terrestrial applications.

The wide variety of primary energy sources and conversion technologies which are available to produce electricity raises difficult questions when trying to compare their relative environmental merits.

Even if some electricity production can be avoided through energy efficiency programs for instance, such programs cannot fill all electricity capacity requirements and also have their own environmental impacts which must be accounted for.

8 For a full discussion of this issue, see Ch.3: *"Comparative Environmental Analysis of Power Generation Options"*.

9 Emitting GHG when hydrogen is extracted from fossil fuels, such as natural gas or gasoline.

The comparison of power generation options from an environmental perspective must take into account two major aspects: the comprehensiveness of the analysis, and the ancillary services provided by the various electricity generation technologies.

Comprehensiveness

A cursory evaluation of impacts tends to focus only on the impacts of the power plant, thereby omitting the inevitable impacts upstream and downstream of the production cycle. The impact of an oil-based thermal power plant must include the impacts associated with oil extraction, oil transportation and storage, etc., as these activities are unavoidable steps in the process of producing electricity from oil. The same applies to gas or coal based electricity production. The impacts of a photovoltaic plant must include those of the chemicals that enter into the PV cell's manufacture[10].

In short, the life-cycle of the production process must be considered when comparing the environmental impacts of electricity options.

Ancillary Service

Although electricity may be produced from a dozen or more primary energy sources and many more conversion technologies, the end result is not the same. All these processes produce electricity, but the ancillary services they provide are not identical, in terms of conversion efficiency, flexibility of production, or capacity to follow demand.

For example, car batteries provide electricity instantly at the turn of a key, but it is inconceivable to provide electricity for a city based on batteries. Therefore the electric battery is well suited for certain applications – instant, low-voltage power – but unsuited for large-scale supply. Another example is photovoltaic or windpower: both are relatively low impact sources, but only produce electricity during daylight or when the wind blows; these are intermittent, variable sources of generation which cannot produce electricity on demand. The service they provide is therefore much more limited than other options.

The examples above illustrate how ancillary services rendered by electricity production options may vary. Some options offer limited services, other options provide many.

When comparing the environmental impacts of power generation options, it is essential to take into account the kind of ancillary services the option provides.

A simple analogy is the environmental comparison between a bus and a car. A bus generates much more pollution than a car. This being true, should we replace buses by cars? The level of service provided by a bus (moving 40 people) is higher than that of a car (moving 4 people). Which mode of transportation has the greatest environmental impact? Based on the service provided by the technology, the private automobile has much larger environmental impacts than the bus[11, 12].

It is interesting to note that technology is not the only aspect to consider when assessing environmental impacts: management is just as important, as an empty bus moving through a city (good technology and poor management of public transit routes) provides no service, and therefore has a much higher environmental impact than the private automobile.

In summary, the exceptional ancillary services provided by hydropower – reliability, power on demand, electricity available in a few minutes from a cold start, energy storage in reservoirs, etc. – makes hydropower a possible producer of base load, of peak load, of voltage and frequency regulation, of energy storage and of other services. These ancillary services are not always available with other power generation options. They must therefore be considered and integrated into the comparative environmental analysis of electricity production options.

10 IEA. 1998. *Benign Energy? The Environmental Implications of Renewables.* OECD/IEA. Paris.

11 However, the automobile offers other services that buses cannot provide, such as flexibility of destination and schedule.

12 Environmental assessments carried out for transportation projects frequently compare various transportation systems (car, bus, rail, air, etc.) on a relative basis such as impact per passenger/km (e.g., pollution or accidents per passenger/km) in order to make fair comparisons between the various options. The same logic must apply to the comparison of power generation systems (e.g., impacts per kWh).

7.2.3 Comparative Life-cycle Environmental Performance of Hydropower

The comparison of the relative environmental performance of power generation systems on the basis of *life-cycle analysis* (LCA) does not eliminate the need for value judgements and arbitration. This is due to the fact that many impacts are impossible to compare directly (e.g., local land use issues for hydropower versus the management of radioactive wastes for nuclear power, or versus the management of global and regional atmospheric issues for coal, oil and natural gas based power). Another constraint of life-cycle analysis is that it cannot easily account for "non-quantifiable" or "qualitative" impacts, such as landscape, social, or biodiversity issues.

Carrying out life-cycle assessments according to decreasing levels of impacts (e.g., global, regional and local) may be a good way to define priorities. Modifications to a global biochemical cycle (such as the carbon cycle) will ultimately produce significant changes at all levels (global, regional and local). Global climate change is likely to be the source of major impacts on biodiversity and human health. Carrying out life-cycle assessments on the basis of such levels of priority would clearly favour any renewable energy source over the various forms of fossil fuel power generation.

To conclude on the comparative life-cycle environmental performance of hydropower, it is important to note that most comparisons of systems are unfair to hydropower for the following reasons:

- the multipurpose character of many reservoirs increase their environmental impacts, while the related benefits are often neglected; social concerns are extremely variable from one project to another

- the reliability that hydropower provides the electricity network is often forgotten

- since "best available technology" is not an appropriate concept for hydropower, comparisons tend to compare statistics of old hydropower projects with new recent thermal power projects.

However, despite this "structural" negative bias, hydropower still comes out ahead of other electricity systems in most life-cycle comparisons. (See Table 36: Synthesis of Environmental Parameters for Electricity Options.)

Table 36: **Synthesis of Environmental Parameters for Electricity Options**

Electricity Generation Options (classified by level of service)	**Energy Payback Ratio**	**Greenhouse Gas Emissions** (kt eq.CO_2/TWh)	**Land Requirements** (km^2/TWh/y)	**SO_2 Emissions** (t SO_2/TWh)	**NO_x Emissions** (t NO_x/TWh)	**NMVOC Emissions** (t/TWh)	**Particulate Matter Emissions** (t/TWh)	**Mercury Emissions** (kg Hg/TWh)
Options capable of meeting base load and peak load								
Hydropower with reservoir	48 to 260	2 to 48	2 to 152 projects designed for energy production	5 to 60	3 to 42		5	0,07 methylmercury in reservoirs
Diesel		555 to 883		84 to 1 550	316+ to 12 300	1 570	122 to 213+	
Base load options with limited flexibility								
Hydropower run-of-river	30 to 267	1 to 18	0,1	1 to 25	1 to 68		1 to 5	
Bituminous coal: modern plant	7 to 20	790 to 1 182	4	700 to 32 321+	700 to 5 273+	18 to 29	30 to 663+	1 to 360
Lignite: old plant		1 147 to 1 272+		600 to 31 941+	704 to 4 146+		100 to 618	2 to 42
Heavy oil without scrubbing	21	686 to 726+		8 013 to 9 595+	1 386+	22+		2 to 13
Nuclear	5 to 107	2 to 59	0,5	3 to 50	2 to 100		2	
Natural gas combined-cycle turbines	14	389 to 511		4 to 15 000+	13+ to 1 500	72 to 164	1 to 10+	0,3 to 1
Large fuel cell (natural gas to hydrogen conversion)		290+ to 520+		6	0,3+ to 144	65	2 to 6+	
Biomass: energy plantation	3 to 5	17 to 118	533 to 2 200	26 to 160	1 110 to 2 540	89+	190 to 212	0,5 to 2
Biomass: forestry waste combustion	27	15 to 101	0,9+	12 to 140	701 to 1 950		217 to 320	
Intermittent options that need a backup production (such as hydro with reservoir or oil-fired turbines)								
Windpower	5 to 39	7 to 124	24 to 117	21 to 87	14 to 50		5 to 35	
Solar photovoltaic	1 to 14	13 to 731	27 to 45	24 to 490	16 to 340	70	12 to 190	

7.2.4 Environmental and Social Impacts of Hydropower: State of Knowledge and Challenges[13]

As for all other major power generation options, hydropower is the source of both significant and unavoidable environmental and social impacts. The most important unavoidable impacts of hydropower are generally related to the flooding of land in the impoundment zone upstream of a dam and to changes to water flows and water levels downstream of a dam. The nature and severity of such impacts are highly site specific and tend to vary in scale according to the size and type of projects.

The section that follows briefly discusses the state of knowledge with respect to the avoidance or mitigation of social and environmental impacts of hydropower. It presents a summary overview of the challenges that still confront hydropower designers, builders and operators.

Socioeconomic Impacts of Hydropower

The management of socioeconomic impacts and benefits constitutes one of the major challenges associated with hydropower projects, particularly in countries affected by political instability, competing water needs, and a scarcity of resources. Several hydroelectric projects still await completion or have been abandoned because of controversies related to socioeconomic concerns, such as:

- poorly managed involuntary displacement and loss of livelihoods for populations living within or downstream of the impoundment zone
- loss of means to support traditional ways of life, particularly in the case of culturally vulnerable indigenous or ethnic/religious minority groups that are largely dependent on locally available land and natural resources
- higher incidences of waterborne or behavioural diseases, particularly among vulnerable communities
- low regional economic development returns and inadequate redistribution of project benefits to affected communities.

For current planning and management practices for each of these issues, the reader may refer to Vol III, Appendix F of the present report. Even if substantial progress has been made in planning for and managing these concerns, there still remain problems to be addressed. These problems are briefly summarised hereafter.

Succeeding in Improving Livelihoods Following Resettlement

Reservoir impoundment and construction works may involve both displacing people and/or jeopardising their livelihoods. Managing such a process therefore requires both the resettlement of displaced communities and their socioeconomic rehabilitation (e.g., the rebuilding of displaced people's livelihoods through community development). To be successful in such an undertaking, the objective for proponents must be to ensure that hydropower projects result in improved standards of living for affected people. Moreover, proponents must count on effective legislative and institutional management, which pose the following challenges:

13 For a full discussion of this issue, see IEA. May 2000. *Hydropower and the Environment: Present Context and Guidelines for Future Action.* Vol. III: Appendices:
- *Appendix D:* "*Physical and Chemical Environment*"
- *Appendix E:* "*The Flora and the Fauna*"
- *Appendix F:* "*Socioeconomic Environment* "

and

IEA. May 2000. Annex III - Subtask III/6, *Hydropower and the Environment: Effectiveness of Mitigation Measures.*

- how to foster the adoption of appropriate regulatory frameworks for resettlement and rehabilitation (R&R) in countries where local traditions and sociopolitical contexts are not adapted to such undertakings

- how to build institutional capacities for R&R (institutionalised project-planning processes, reinforced land management capabilities, increased public participation in the decision-making process) in a context of scarcity of human and financial resources

- how to provide necessary land-based and non-land based income restoration programs for R&R in a context of scarcity of available land and financial resources

- how to ensure the design and implementation of long-term integrated community development programs in a context of political instability or neglect.

Minimising Impacts on Culturally Vulnerable Communities

Hydropower projects in indigenous or traditional resource based areas can have far-reaching cultural and social effects at the community level. The extent of such impacts is difficult to ascertain, considering the number of outside influences to which communities often are already subjected. Nevertheless, communities often perceive such projects as being destructive or a threat to their culture.

To successfully minimise impacts on such communities, the objective for proponents should be to ensure that hydropower projects provide sufficient time and resources to adapt to changing conditions, as well as alternative means to support traditional ways of life where required. There are several challenges to reach such an objective, including:

- how to provide culturally vulnerable communities with sufficient time and resources to adapt to changing conditions, when both available time and resources are limited

- how to ensure long-term financial support of economic activities and community services that are adapted to local cultures, without causing long-term dependence on outside sources of funding.

Improving Public Health

Higher incidences of waterborne diseases due to modifications to hydrological systems and higher incidences of behavioural diseases due to population displacement are possible consequences of the presence of a man-made reservoir, particularly in tropical or subtropical environments. To successfully minimise such impacts, the objective for proponents should be to ensure that hydropower projects result in improved health conditions for affected people. This poses certain difficulties, such as:

- how to build the required regional and local institutional capacities for an effective public health systems in a context of scarcity of resources and possible lack of government infrastructure.

Sharing of Development Benefits

Hydropower projects, like many other infrastructure projects, sometimes result in an inadequate redistribution of project benefits to locally affected communities. To successfully optimise local development benefits, and even more so in less developed countries where local populations may be more economically vulnerable, the objective for proponents should be to ensure that affected communities become project beneficiaries. However, the lack of political will and competition for resources are frequently an obstacle to reach such an objective. This poses certain difficulties, such as:

- how to ensure an equitable distribution of long-term development benefits and costs between affected populations and project beneficiaries, in a context of competing needs, limited political will and often insufficient resources.

Environmental Impacts of Hydropower

The understanding and management of environmental impacts associated with hydropower projects has progressed considerably over the last twenty years, as a result of studies, of monitoring, of follow-up, and of increased regulatory requirements. Experience gained worldwide in terms of improved project planning and design, as well as in the development of comprehensive environmental mitigation programs, have helped avoid or reduce the severity of a large number of impacts typically associated with hydropower.

For a comprehensive overview of current environmental knowledge and management practices, the reader may refer to Vol III, Appendices D, E and F of this report. Even if substantial progress has been made in designing hydropower projects and managing their environmental impacts, challenges still remain to be addressed. The main ones are briefly presented hereafter.

- *Integrating the preservation of biodiversity and productivity in project design:* The need to preserve biodiversity and productivity, and to minimise the loss of ecologically valuable habitats through the restoration or improvement of other habitats poses new challenges to hydropower project designers. Issues to be addressed include the conservation of rare or protected species, maintaining aquatic continuums, minimising habitat fragmentation and identifying better biophysical indicators.

- *Optimising flow regimes downstream of a reservoir:* Optimising flow regimes downstream of a reservoir poses complex technical and political problems. It is the subject of ongoing research. Such optimisation must take into account water uses upstream and downstream of the dam, power generation requirements and the needs of aquatic or riverine habitats. Optimisation is particularly challenging when communities rely on subsistence fishing or seasonal flooding of fields downstream of a reservoir.

- *Improving fish passages for valuable migratory species at hydropower dam sites:* Improvements in turbine, spillway, and overflow design have proven to be highly successful in minimising fish mortality and injury. Existing fishways and fish ladders installed at hydropower dams are in some cases rather ineffective. Designing effective fishways or fish ladders for migratory or anadromous species still pose complex problems and is also the subject of ongoing research.

- *Improving sedimentation management in reservoirs:* In general, large dams and reservoirs are designed for an operating life of about 100 years, but about 10% of hydropower reservoirs face sedimentation problems. Periodic flushing can prolong the life of a reservoir, but many dams are not equipped for this. In certain cases, severe reservoir sedimentation leads to sediment deficits and increased river bank and river bed erosion in downstream rivers and estuaries. Avoiding the siting of dams in areas characterised by high erosion rates, and the planting and conservation of forested areas in upstream catchment areas can also reduce sedimentation in reservoirs, but is not always easy to sustain on a long-term basis.

- *Limiting water quality problems through good site selection:* When a reservoir is located in dense forest areas, particularly in tropical regions, a very large amount of biomass and soils may be submerged. In certain conditions, this may lead to oxygen depletion and to anoxic conditions in the reservoir. This in turn can result in the formation of toxic substances such as hydrogen sulphide (H_2S) or heavy metals in the anoxic layer of the reservoir, to fish deaths when toxic substances rise to the surface, to increased water acidity levels, and to problems in the downstream area (bad odour, methane emissions, toxicity) which may restrict water uses. Even if pre-impoundment forest clearing and water storage management measures (such as selective multi-level intakes) can reduce such problems, further consideration must be given to reservoir water quality management at the early design stage of a project through good site selection, the use of better predictive modelling and more widespread reservoir water quality monitoring.

- *Managing reservoir eutrophication and water contamination problems during operation:* During the operation phase, water quality problems in reservoirs are caused primarily by the inflow of organic material and nutrients and/or toxic substances due to untreated domestic sewage and runoff from agricultural or industrial uses, or due to activities in the reservoir itself, such as aquaculture. Such inflows may lead to eutrophication which can make water unsuitable for recreation purposes or as drinking water and to the proliferation of aquatic weeds. Establishing effective multi-stakeholder watershed management in the catchment area and downstream of the reservoir, enforcing sound land use management policies and building sewage treatment systems are effective means to reduce such problems in reservoirs, but are not easy to implement and sustain on a long-term basis.

7.2.5 Ethical Considerations[14]

Over the past two decades, the role played by large-scale hydropower projects in global development, particularly in the developing world, has been increasingly questioned. In a context of mounting uncertainties about the availability and quality of water resources in many regions of the globe, using water (viewed as a common good) to produce energy must be justified not only on the basis of national or local economic benefits in general, but also on the basis of the quantity and quality of expected benefits for a wide variety of regional and local stakeholders (local communities, regional or international environmental resource-based interest groups, etc.).

These stakeholders express a wide diversity of viewpoints. In many cases, stakeholders do not share similar values, codes of conduct or interests. Conflicts may arise when the concerns of certain groups are ignored or rejected, particularly when they involve fundamental issues of allocation and control over resources and of distribution of wealth. In most societies, resolving ethical dilemmas surrounding such issues (e.g., establishing a consensus in regards to what is acceptable) often requires prolonged and difficult discussions to identify widely accepted moral, social, economic and environmental trade-offs.

In view of the above, what are the main ethical dilemmas that may be associated with hydropower development? Such dilemmas generally fall into one of four categories.

- *The conservation of natural resources versus the satisfaction of essential human needs:* Opponents claim that major hydropower projects are unacceptably disruptive to the balance of natural and man-made components of river systems and incompatible with the need to conserve or restore biodiversity in valued watersheds. Proponents claim that widespread access to electricity plays a key role in promoting development (lessening such ills as harvesting wood for household or industrial needs, for example), and that all sources of power generation entail short- or medium-term loans on natural capital as well as certain irreversible ecosystem impacts.

- *The increased production of wealth in order to support growing needs versus the fair distribution of accumulated wealth:* Opponents claim that major hydropower projects lead to reduced levels of social justice because they subsidise urban, industrial or agribusiness interests to the detriment of locally affected rural populations. Proponents claim that such projects are required in order to support the development of modern industries and services and thereby generate sufficiently important surpluses to be able to assist poor rural populations.

- *The rights of small numbers of locally affected populations versus the rights of larger numbers of potential beneficiaries:* Opponents claim that large water resource development and hydropower projects frequently violate the rights of locally affected populations and unnecessarily displace and lower the standards of many people in poor rural areas. Proponents claim that the number of people benefiting economically and socially from such projects is much greater than those whose lives may be disrupted and that the large majority of hydropower projects yield a variety of benefits that far exceed their costs, including the costs of adequate measures to mitigate their adverse environmental and social impacts.

14 For a full discussion of this issue, see Ch.5: *"Ethical Considerations"*.

- *The standards of international donor and lending agencies versus the standards of less developed beneficiary countries:* Opponents claim that internationally funded water resource development and hydropower projects do not always apply the same stringent environmental and social standards in less economically developed beneficiary countries as those that would be required in more economically advanced countries. They advocate the prior development of appropriate political processes and institutional frameworks in order to democratise and decentralise the decision-making process for water resource and land-use management. Proponents claim that international environmental and social standards are now increasingly applied to all development projects, even if they must be adapted to a certain extent to local cultural, political, institutional and regulatory realities and contexts.

In order to confront these dilemmas in a responsible fashion, what are the main ethical *principles* or *rules of conduct* that should be applied to future hydropower development projects? The five following ethical principles are generally recognised as being applicable to most development projects.

- *Stewardship:* Proponents of hydropower projects should demonstrate their willingness to act as stewards of the watersheds where they intervene, by properly managing available environmental resources in a sustainable way. They must therefore be prepared to contribute to a system of checks and balances – such as community-based monitoring and follow-up committees. They must also periodically validate the soundness of resource management measures.

- *Participatory Decision-Making:* The most equitable solutions generally arise from discussions that give everyone a chance to be heard. A participatory process can also ensure that important factors which might otherwise be overlooked are fully taken into account. Finally, it can strengthen the moral authority and legitimacy of the resulting decision. Participatory processes do present challenges of their own. The question of who is a legitimate representative of a group or a stakeholder and hence entitled to participate is not always an easy one. Some important interests, for example those of society as a whole, may not even be represented by a spokesperson at the table. Some participants, including the promoter, may have strategies of all sorts that result in the choice of an alternative selected in advance. Just because an interested party participates in the process does not of itself produce an optimal result. Whatever the merits or disadvantages of participatory decision-making may be, the fact is that in many countries citizens have increasingly challenged the power and authority bestowed on their elected officials and the bureaucracy. Value systems have evolved, and those who are governed want to participate more fully in decisions made by those who govern.

- *Precautionary approach and control:* To build trust and credibility, proponents and regulators of hydropower projects must adopt a responsible and cautious decision-making attitude based on the study of the foreseeable consequences of their actions. This requires that in-depth assessments be carried out to determine the possibility of irreversible impacts on water quality and life-sustaining systems, on the health and safety of local populations, on the ability of displaced communities to restore or improve their standard of living, and so forth.

- *Fairness and justice:* Supporting sustainable development requires that one act with respect for human dignity and for the right of every human being to develop his or her potential. This means that the benefits and drawbacks of a project that involves the use of limited collective resources must be fairly distributed among beneficiaries and impacted populations, as well as between existing and future generations. Those who benefit from a project must also assume its risks as well as its environmental and social costs. Fairness means that affected populations who do not directly benefit from a project should receive sufficient indirect benefits to be fully compensated for their losses.

- *Optimality:* When the use of a limited collective resource is at stake, optimality refers to the selection of the best available project option on the basis of the factors deemed important by concerned stakeholders. The search for an optimal solution involves a difficult process of balancing pros and cons and identifying trade-offs which, to be credible, must be based on open, inclusive and transparent public discussions. Such a process tends to generate the trust that will be needed subsequently to implement the project in a peaceful social climate.

In view of the above, the social acceptability of future hydropower projects requires that:

- project goals be clearly stated in relative terms (by comparing project benefits and costs to those of other alternatives, including the "no go" option)

- they result in net social development gains in terms of the multiple use of available resources (e.g., improved access to water, irrigation, public health, community services, power, etc.)

- they are the result of a fair, open, inclusive and transparent participatory process

- they include accountability guarantees such as grievance committees to respond to unpredictable or unforeseen issues, as well as funding for as long as there are risks to manage

- affected communities become project beneficiaries, through revenue or equity sharing, for example.

7.2.6 Legal and Regulatory Frameworks and Decision-making Issues[15]

The last outstanding environmental issue related to hydropower involves the environmental decision-making process. In most countries, this process is closely linked to legal and regulatory frameworks, and to the environmental assessment and licensing processes in particular. Environmental assessment (EA) is both a management tool and an indispensable aid for decision-making. Its purpose is to help elected officials and project proponents make well-founded decisions, to give clearance or not to a project once its environmental impacts are fully known, and to improve the project design itself. Indeed, EA is not an aim in itself, but an instrument to be used by decision makers to carry out their duties in accordance with relevant legal and regulatory frameworks.

As noted previously, ethical dilemmas frame hydropower development issues. Thus, to be of any use, an assessment of environmental approval processes for hydropower projects must take into account ethical considerations. From a legal perspective, the ultimate goal is to reconcile the three basic requirements (promoting human rights, protecting the environment, and ensuring everyone's right to economic development) that frame hydropower development. The reconciliation of each of these requirements can be pursued by applying a holistic approach. As our review of literature has shown, a holistic approach can prove effective in reconciling the conflicting views of protagonists involved in the environmental approval process by balancing the different concerns of local populations, of groups that promote environmental conservation, and of project proponents.

Chapter 6 outlines and discusses environmental approval processes in the specific context of future hydropower projects. In the future, decision-making processes should not only aim at reconciling stakeholders' perspectives, but must also be efficient and effective for stakeholders and for society at large. An **efficient** process is one that minimises the resources required – time, money, expertise – to achieve a decision. An **effective** environmental process is one in which the relevant environmental and social impacts of a project are correctly and rigorously identified, assessed, and fully taken into account.

Since the Seventies, most countries have created legal and regulatory frameworks to protect their environment, including environmental assessment and licensing processes. They have used these tools to ensure that large infrastructure projects do not cause unacceptable adverse environmental impacts. The appropriateness or importance of such tools is not questioned here. Rather, it is our belief that we have learned from past experiences and can draw certain conclusions and recommendations from these experiences to improve on past practices.

15 For a full discussion of this issue, see Ch.6: *"Legal and Regulatory Framework"*.

In light of the present analysis of the effectiveness and efficiency of regulatory processes that apply to hydropower projects, there is growing concern that environmental approval and licensing processes have become overly rigid and cumbersome in many OECD member countries in particular. In certain cases, such processes impose costs on society and project proponents that are not commensurate with the benefits gained or impacts avoided. Such costs include, among others, excessive information requests, unnecessary operational restrictions and unreasonable delays to project implementation schedules. Such costs may even lead to the cancellation of beneficial projects.

Around the world, the demand for reliable power supplies is steadily increasing. Electricity prices have recently been following upward trends in a number of countries. In part, this reflects insufficient new investments in power generation for a number of years. Because hydropower projects are more affected by uncertainty, including market and regulatory uncertainty, there are fewer new hydropower projects being developed throughout the world. This is regretful in view of the fact that many countries still have abundant hydroelectric resources to develop, combined with increasing needs.

Unduly restraining hydropower development may not be desirable because hydropower may, in many cases, be more environmentally benign than other traditional sources of power. Nonetheless, policy errors are still being made when allocating power generation resources. Investments in power generation currently being planned are, in many parts of the world, mostly thermal electric, which produces greenhouse gases and other air, water and land pollution. Hence, by discouraging investment in hydropower projects, decision makers may inadvertently encourage power generation investments that might be more damaging to the environment than hydropower.

Regulatory reform is required to address certain imbalances and to avoid a poor allocation of resources for power generation. Project proponents, along with governments and non-governmental organisations, share responsibilities with regards to the development and implementation of legal and regulatory frameworks governing hydropower development, including environmental assessment and licensing processes. In our summary and recommendations, we discuss how these various stakeholders could contribute to improve these aspects.

7.3

RECOMMENDATIONS

Based on the above, there are five areas which pose significant challenges to the hydropower sector. These are:

- **Energy policy framework**
- **Decision-making process**
- **The comparison of hydropower project alternatives**
- **Improving environmental management of hydropower plants**
- **Sharing benefits with local communities**

Recommendations and guidelines are proposed for each of these topics. These recommendations, as well as their associated criteria and guidelines, apply to a very broad range of projects. Obviously, all project-related impacts cannot be avoided or mitigated. For this reason, environmental impact assessments, as well as corresponding mitigation, enhancement, compensation, monitoring and follow-up programs, remain essential project planning tools. These recommendations, criteria and guidelines should thus be seen as a guide for planners and operators.

RECOMMENDATION # 1

Energy Policy Framework

Energy is a fundamental sector of a nation's economy. In the same way as countries have health or education policies, a clear view of the energy priorities of a country is required in order to clarify the development context. Such an energy policy may be market-based and competitive – allowing market forces to freely allocate resources – or, at the other extreme, it may be centralised and restrictive, leaving governments to decide what investments should be made in terms of energy development. The point here is not to discuss the relative merit of any single type of policy. Indeed, each nation's energy context is unique, and requires specific approaches at various stages of economic development.

What is recommended here is that each country should clearly set out its energy policy, or at least its energy development strategy, so that the rules are known to all, and that arbitrary decisions are minimised: this is particularly important for hydropower development which requires a long lead-time and expensive engineering / environmental studies prior to producing electricity.

In the coming decades, most future power generation capacity will be privately financed. Private investment seeks the highest return on capital while minimising risks. For the hydropower industry, it is imperative to reduce existing uncertainties regarding changing environmental regulations and open-ended licensing procedures in order to attract investment capital.

Therefore, governments have a significant responsibility with respect to the clarification and simplification of environmental and licensing procedures, as well as to the harmonisation of overlapping agency regulations that apply to hydropower projects[16]. One avenue is to have governments clearly define their energy development strategies in general, and state their positions regarding hydropower development in particular. Such an approach would allow investors to know whether hydropower development is encouraged or not in a given country or jurisdiction, and under what conditions.

RECOMMENDATION # 1

Energy Policy Framework

Nations should develop energy policies which clearly set out objectives regarding the development of power generation options, including hydropower.

- National energy policies should compare electricity generation options fairly, by "internalising" or fully accounting for environmental and social costs.
- Comparison of power generation options should be based on a life-cycle analysis, by assessing impacts on the basis of the services provided by each technology.
- The social, environmental and economic trade-offs required to establish a national energy policy should be supported by public debates and be the result of a consensual approach.

16 Regulations that apply to waterways, land use, fisheries, navigation, recreation, habitat protection, etc.

Energy policies must fully integrate environmental and social considerations. Available tools for integrating such considerations into energy policy decision-making include life-cycle analysis (LCA) for the comparison of power generation options, as well as strategic or sectoral environmental assessment (SEA) which can be combined, if necessary, with hydropower master planning. The main reason for using such tools is to establish a level playing field between power generation options, by "internalising" (or accounting for) the environmental and social costs of each option. Recommendation #1 addresses this issue.

This recommendation is based upon the premise that clear and transparent power supply and transmission strategies should be put forward by governments, industry and civil society in order to avoid the re-questioning of power generation options at the onset of projects. Governments should develop energy strategies in concert with concerned parties so that a general consensus exists prior to project-specific investments.

Energy strategies should be based on political, economic, environmental and social criteria as well as on the principles of sustainable development. The comparison of energy options should take into account the level of energy services, the multiple uses of available resources, the pooling of regional means of power supply and transmission, the life-cycle assessment of energy options, as well as energy efficiency alternatives.

GUIDELINES FOR ENERGY POLICY-MAKING

Countries should consider strategic environmental assessment (SEA) as a planning tool at the national energy policy level

An SEA at the national or regional policy-making stage helps integrate environmental and public concerns into energy policy-making, in order to reconcile development, environmental protection and community rights. One important objective of an SEA for energy policy would be to reduce uncertainties regarding the potential development of hydropower resources by, for example, defining river reaches which should be available for development and, conversely, those reaches protected from water resource development.

Apply the precautionary principle at the national policy level

Decision makers should consider global issues such as ozone depletion, global warming, acid rain precipitations, loss of biodiversity, as important issues when establishing national policies for energy, water and land use. These issues should be addressed and dealt with at the policy level even if scientific uncertainties remain in explaining certain aspects of these phenomena.

RECOMMENDATION # 2

Decision-making Process

The second outstanding issue concerns the environmental decision-making process, e.g., the EA process and the regulatory and legal framework that applies to hydropower development. A decision-making process must be efficient and effective for both the project proponent and society at large. The second recommendation presented below proposes guidelines which address these concerns.

RECOMMENDATION # 2

Decision-making Process

Stakeholders should establish an equitable, credible and effective environmental assessment process that considers the interests of people and the environment within a predictable and reasonable schedule.

This recommendation is based on the premise that stakeholders must be treated in an equitable manner. Therefore, the assessment and licensing of hydropower projects should be based on a credible and effective decision-making process, with established rules and clear responsibilities for all stakeholders.

The decision-making process must help identify and reject the worst project alternatives, in order to retain the best alternative. The process should ensure that the environmental reviews and approvals required for each project are completed within a reasonable time schedule. Thus, the process should be directed towards decision-making at the earliest stages of project planning, so that stakeholders know as soon as possible if the project is good enough to be implemented.

This is particularly important in a context of global restructuring of the electricity sector, with increased competition between electricity producers. Unreasonably long environmental assessment and licensing processes for hydropower projects translate into a competitive disadvantage for hydropower producers compared to other forms of power generation, including, for example coal-fired power plants.

Time delays generate significant costs for all participants in a hydropower project: Delays can lead to significant social and economic costs for concerned communities. When a hydropower project is announced in an area and then postponed for regulatory and administrative reasons, uncertainty may set in. Such uncertainty may subsequently lead to the freezing of local investments as communities, governments, businesses, and individuals refrain from committing resources in an area that might be flooded in the future. Although this is true for any type of reservoir impoundment project, whether it is delayed or not, additional delays simply compound the problem.

Governments can also incur costs when decisions regarding hydropower projects are unnecessarily delayed: loss of revenue from delayed investments, direct costs due to lengthy procedures, etc. Similarly, as project proponents are likely to lose money and investment opportunities if a project is delayed, they often prefer to know as early as possible in the design process whether a project is acceptable or not in order to minimise such losses.

The key then, is to improve the decision-making process for hydropower assessment and licensing in such a way as to effectively protect the environment and local communities without unfairly burdening project proponents with procedural uncertainties and unreasonable delays.

The second recommendation presented above is supported by the following proposed Guidelines for Decision-Making.

GUIDELINES FOR DECISION-MAKING	P	C	O	R
Bilateral and multilateral institutions should increase their support for EA institutional strengthening and capacity building In addition to national regulatory and legal frameworks for EA, qualified human resources are required to establish a credible and efficient environmental management culture. International institutions already provide such services. These must be encouraged, particularly in countries where needs are greatest.	●			
Countries without a compulsory EA process should develop and adopt one All countries should enact laws that make EA mandatory for large infrastructure or energy projects. It should be easier to encourage countries to enact a legislative framework by pointing to the international treaties that they have signed. Laws and regulations must be implemented, and countries should have the appropriate resources to carry out the assessments.	●			
Countries that have not yet adopted an EA policy should review the past experience of both developing and developed countries in EA implementation. The aim here is to adopt pragmatic approaches so as to avoid major errors of the past. Sharing past experiences in implementing EA is a possible route for countries which share similar socioeconomic conditions. Some developing countries have had over a decade or more of practical experience in EA implementation, which could provide useful lessons for other countries with less experience in such matters.	●			
Develop an international procedure for the environmental management of existing dams, reservoirs and hydroelectric power stations. The ISO (International Standards Organisation) or the IEC (International Electrotechnical Commission) could serve as focal organisations to develop such a procedure. Such an international standard of management could help avoid many conflicts regarding competing water uses. It would also provide a common framework for dam management whatever the institutional context.			●	
The power sector should implement recognised environmental management systems (EMS). ISO 14001 is an example of a recognised international standard in environmental management that pursues continuous improvements in environmental performance. The environmental management system (EMS) selected could be certified or registered by international organisations.	●	●	●	●

LEGEND:
P: Planning – **C**: Construction – **O**: Operation – **R**: Refurbishment

GUIDELINES FOR DECISION-MAKING	P	C	O	R
The power sector should adopt and enforce codes of conduct regarding human rights and environmental protection These codes are important to ensure that EAs are adequately conducted and human rights respected across the power industry, particularly in regions where minimum standards are non-existent or inadequately enforced. The codes should provide guidance in environmental management, public participation, and conflict resolution.	●	●	●	●
EA processes should address both the adverse impacts and the benefits of a hydropower project, in a balanced analysis. Trade-offs between social, environmental and economic goals are inevitable in a development process. EA as a decision-making tool should reflect this. The focus of the EA process must be on assessing possible trade-offs, and proposing concrete solutions such as mitigation, enhancement and compensation measures.	●			
Quality of work is the foremost criterion for EA studies, which must be based on recognised scientific methods and factual information As long as a systematic and scientific methodology is applied to EA studies, it matters little who is responsible for conducting the studies. When scientific uncertainties remain, they should be stated in the reports and adequately explained, letting decision makers arbitrate such issues.	●	●	●	●
On issues that raise the most concerns, consult recognised experts Under certain circumstances, such as scientific uncertainty or polarisation of a debate, it may be desirable to consult with experts who are deemed acceptable by most parties to present an external perspective regarding a specific issue.	●	●	●	●
Environmental assessment at the project level must concentrate on project issues – e.g., selection of alternatives, assessment of impacts, mitigation, etc.– and not on policy issues – e.g., a nation's energy, water or land-use policy Project level EA cannot substitute for a legislative assembly and democratic debate on policy issues. Policy issues must be debated at the national level using tools such as SEA, Regional Environmental Assessment, etc.	●			
Focus hydropower project assessment on key issues through project scoping The EA process must focus on issues that are truly important for a given project. Project scoping helps identify the main issues to be assessed at the onset of the EA process. Scoping should reduce the length of the assessment process by avoiding the study of trivial concerns. Selection of the key issues must be undertaken on the basis of public participation and of established science, integrating past experience from follow-up studies. When adequately implemented, this requirement should help avoid the production of unnecessarily "encyclopaedic" environmental impact assessment reports.	●			

GUIDELINES FOR DECISION-MAKING	P	C	O	R
Design each stage of the EA and licensing processes for hydropower with a view to reducing delays Delays mean uncertainty, and uncertainty means added costs and a competitive disadvantage for hydropower project proponents. In a competitive energy market, the EA process for a hydropower project should not take longer than the EA process required for any other type of power generation option. EA processes must be decision-oriented and carried out within a reasonable time-frame. Mandatory deadlines throughout the EA process are excellent ways to limit uncertainty and unreasonable delays for all stakeholders.	●			
When more than one EA process applies, the EA must be consolidated into a single procedure in order to avoid the duplication or overlapping of efforts In some countries, EAs may be conducted by two or more levels of government. As countries form regional alliances, the issue of EA may even be addressed at the regional, national or even supranational level. Decisions by one level of government often are non-binding for other levels of government. Timing of the various assessments often do not coincide, increasing uncertainty and delays in decision-making. A unified EA process means one set of guidelines, one single panel and, ultimately, one decision and one set of conditions.	●			
Encourage public participation in the EA of power projects Proponents and governments should solicit public participation from the onset so that the scope and scale of the studies can be determined with the help of concerned communities and environmental groups. In addition, when the findings of the various studies are obtained, they should be made readily available to the public. Finally, the public should be involved in developing mitigation, enhancement and compensation measures from the onset of the project and throughout the EA process, with the assistance of appropriate tools and available technology.	●		●	
Adopt a code of basic procedural rights for public meetings or hearings to ensure that all stakeholders are treated fairly and that their roles are clearly set out Stakeholders in a debate must be treated in a manner that allows for arguments and counter-arguments to be exposed and debated openly. Procedures should allow for any stakeholder – including project proponents, opponents, government representatives and the public – to be challenged on their arguments, in order to allow the general public to build an informed opinion about a project.	●			

RECOMMENDATION # 3

Comparison of Hydropower Project Alternatives

If the decision is taken at the policy level to develop hydropower, then criteria must be available for both government agencies and developers to provide for *an effective comparison of hydropower project alternatives.* Such criteria are required in order to eliminate bad hydropower projects from the very onset of project planning.

Engineers and economists can apply readily available tools to quickly assess the technical and economic merits of project alternatives, and to prioritise such alternatives. Similar tools should be developed to prioritise alternatives from an environmental and social perspective at the preliminary design stage, when only limited field data is available.

The traditional process of identifying the best project alternatives mostly on the basis of technical and economic considerations and *subsequently* undertaking an environmental impact assessment (EIA) for the selected project is ineffective and a waste of resources, for a number of reasons.

- A good project from a business and technical perspective might be a poor project from an environmental or social viewpoint. Engineers must be aware of the social and environmental consequences of their choices when they design project alternatives.

- Hydropower project planning requires considerable resources. Once these resources are set in motion, it becomes harder for both proponents and opponents to modify or reverse the process.

- Mitigation of social and environmental impacts carries significant costs. Project planners try to minimise such costs and therefore have an incentive to know which project involves the least impacts.

- It is very time-consuming to select project alternatives without taking into account environmental considerations, then prepare the EIA, then defend the selected project, then modify or abandon the proposed project to minimise environmental damages. An alternative process in which the worst environmental alternatives are quickly abandoned should reduce the time required to prepare the EIAs. It should also limit the risk of project cancellation or of having to undertake major changes to project design following the EIA.

Recommendation # 3 proposes 10 specific social and environmental criteria to compare and select the best project alternatives, in parallel with economic and technical analyses.

RECOMMENDATION # 3

Comparison of Hydropower Project Alternatives

Project designers should apply environmental and social criteria when comparing project alternatives, in order to eliminate unacceptable alternatives early in the planning process.

A Proposal

The best way to manage impacts is to avoid them in the first place. This third recommendation proposes a list of ten environmental and social criteria to rapidly assess the comparative merits of various project alternatives, helping eliminate those options which present unacceptable impacts. These criteria are presented below.

Project alternatives vary in terms of river basins, dam sites, operation levels, plant factors, and other considerations, including "no-go" options. Since environmental, social and political issues may be as constraining as technical or economic concerns, these alternatives should be presented and discussed with stakeholders as early as possible in order to incorporate in the planning process the social, political and economic dimensions surrounding the potential projects.

The engineering process for selecting preliminary alternatives requires that rapid assessments and decisions be made with minimum fieldwork. It is therefore important to develop tools, such as the ten criteria below, to quickly assess the *relative merits* of project alternatives on environmental and social grounds. Such tools can provide a timely input to the iterative process leading to the selection of project alternatives. These criteria may also be useful for regulators when assessing hydropower alternatives.

Such comparisons must also take into account the level of service provided by each project alternative. This screening process should not replace the detailed inventories which might be required at a later stage of an EA.

There is no order or priority in the checklist presented below.

CHECKLIST of 10 Screening Criteria to Compare Project Alternatives	**COMMENTS**	**EXAMPLES**
Prioritise alternatives on already developed river basins	In several countries, sites with a high potential are often already developed. However, the potential of such sites is not always completely exploited. Therefore, before developing new sites on wild rivers, the residual potential of regulated rivers should be analysed, especially because such rivers often offer less impacting project alternatives. However, the addition of new installations on regulated rivers can lead to cumulative impacts and harm the remaining habitats in a river basin. Proper care should be taken to ensure the preservation of portions of river basins in order to satisfy the needs of existing species.	Several hydropower producers optimise existing hydropower plants and the use of watersheds by upgrading plants or increasing energy production of existing plants through river diversions. (Source: Hydro-Québec)
Prioritise alternatives that minimise the area flooded per unit of energy (GWh) produced See: Chapter 1, Sec 1.2.4 Small, Mini and Micro Projects. *The Large Dam Versus Small Dam Debate*, p.20	It is generally recognised that the environmental impacts increase as the area flooded increases. The selected site and project design should thus tend towards minimising the flooded area *per unit of energy produced* (km^2/GWh), since impact avoidance is always more effective than applying mitigation measures.	During the design phase of the Sainte-Marguerite-3 project in Québec, Canada, the flooded area was reduced by 20% (from 315 to 253 km^2) for a 4% reduction in energy (from 2.9 to 2.8 TWh). (Source: Hydro-Québec)

SCREENING CRITERIA	COMMENTS	EXAMPLES
Prioritise alternatives that do not pose significant threats to vulnerable social groups See: Vol. III. APPENDIX F: SOCIOECONOMIC ENVIRONMENT, Sec. 3.6 Impacts on Vulnerable Minority Groups	1. Prioritise project alternatives that do not affect vulnerable social groups. 2. Project alternatives that affect vulnerable social groups may be acceptable if they include a comprehensive social/cultural enhancement program to manage and monitor the risks. Such programs must be planned and implemented jointly with the concerned communities. Prioritise project alternatives that offer the best possibilities of protecting human rights, enhancing local cultures and developing economic partnerships. 3. Avoid project alternatives that present significant threats to vulnerable social groups that cannot be adequately mitigated.	Project alternatives that are negotiated with, and accepted by, vulnerable social groups minimise adverse social and political impacts.
Prioritise alternatives that minimise public health risks See: Vol. III. APPENDIX F: SOCIOECONOMIC ENVIRONMENT, Sec. 3.1 Impacts on Human Health	1. Prioritise project alternatives that enhance public health or that avoid public health risks. 2. Project alternatives posing potential public health risks may be acceptable if they include a comprehensive public health program to manage and monitor such risks. Prioritise project alternatives that offer the best possibilities of improving local health conditions. 3. Avoid project alternatives that present significant public health risks beyond the institutional capacity required to properly manage them.	In tropical countries, a project alternative which minimises breeding areas for malaria-transmitting mosquitoes should be prioritised. Properly selecting the maximum reservoir level and maximum drawdown can help avoid the formation of seasonal stagnant water pools.
Prioritise alternatives that minimise population displacement See: Vol. III. APPENDIX F: SOCIOECONOMIC ENVIRONMENT, Sec. 4. Resettlement	1. Prioritise project alternatives that avoid displacing people. 2. Project alternatives that involve population displacement in numbers manageable with the available resources may be acceptable if a comprehensive resettlement and rehabilitation plan is developed and implemented. Prioritise project alternatives that offer the best possibilities of improving local living standards in the short and long run. 3. Project alternatives that involve population displacement must be avoided when the number of people displaced goes beyond the institutional capacity to properly manage resettlement and rehabilitation.	In Java, one design alternative for the Saguling reservoir required displacing thousands of people. Lowering the maximum design level of the reservoir by a few metres reduced resettlement significantly. (Source: PLN) In Finland, the headwater level was lowered by one metre from the preliminary plan of the Kokkosniva Project to save the Suvanto village from being flooded. (Source: Kemijoki Oy)

SCREENING CRITERIA	COMMENTS	EXAMPLES
Prioritise alternatives that avoid designated natural and human heritage sites See: Vol. III. APPENDIX E: THE FLORA AND FAUNA, Sec. 4 Biological Heritage. *Protected Areas* And: Vol. III. APPENDIX F: SOCIOECONOMIC ENVIRONMENT, Sec. 5.5 Impacts on human heritage and landscapes	Protected natural and heritage sites are by definition exceptional. Selected alternatives should avoid development in these sites.	In the Aurland II L Project in Norway, transmission line routes were set up in order to avoid valued recreation areas. (Source: Annex III, ST1 report) In the Kurkiaska Project in Finland, the proposed power plant was relocated away from the scenic Porttikoski canyon and cannot now be seen from the river. (Source: Kemijoki Oy)
Prioritise alternatives that avoid the disappearance of known rare, threatened, or vulnerable species and their habitats See: Vol. III. APPENDIX E: THE FLORA AND FAUNA, Sec. 4. Biological Heritage. *Protected Areas*	In a context of preservation of biodiversity, the rare, threatened or vulnerable species are the object of close attention. The development of hydroelectric projects should not compromise the survival of such species, should avoid as much as possible the habitats which support them and allow for their preservation in the long term.	In the Okumino Project in Japan, the development of a daily pumped-storage plant threatened some endangered species and protected areas. All technical facilities were therefore constructed underground so as not to affect rare plants. (Source: Annex III, ST1 report)
Prioritise alternatives that minimise development in high quality habitats See: Vol. III. APPENDIX E: THE FLORA AND FAUNA, Sec. 4. Biological Heritage	Habitats are not of equal quality, some are poorer, others richer. In richer habitats, rates of reproduction are usually much higher than death rates. As these habitats support large numbers of individuals from various species, they should be protected as much as possible.	In the upgrading project of Rivière-des-Prairies in Québec, Canada, one of the key environmental issues was the expected negative impact on fish spawning. Creation of new spawning grounds was implemented and successful. (Source: Annex III, ST1 report)

SCREENING CRITERIA	COMMENTS	EXAMPLES
Prioritise alternatives that will maintain an ecological flow [17] See: Vol. III. APPENDIX D: PHYSICAL AND CHEMICAL ENVIRON-MENT Sec. 2: Impact of Streamflow Control on Hydrologic Regime And: Vol. III. APPENDIX F: SOCIOECONOMIC ENVIRONMENT, Sec. 1.3 Changes to Downstream Land Uses	The development of a hydropower project on a river can modify the downstream flow regime in different ways, by reducing, increasing or regulating the flow. Because ecological and biological processes are tightly linked to the flow regime and because local populations often rely on the river flow for many uses, alternatives with characteristics that keep the river as close as possible to the natural regime should be prioritised.	The dam in the Hunderfossen HPP in Norway became a barrier to migratory and spawning trout. The fish ladder was unsuccessful, as reduced river flow limited fish migration. Trout restocking turned out to be less successful than expected. An increase in the minimum flow downstream, at certain times to trigger migration, improved the situation. (Source: Annex III, ST1 report)
Prioritise alternatives with lower sedimentation risks See: Vol. III. APPENDIX D: PHYSICAL AND CHEMICAL ENVIRONMENT Sec. 4 Erosion and Sedimentation in Reservoirs, Downstream and in Rivers with Modified Regimes	Hydraulic changes resulting from dams and reservoirs on a river system may increase the process of sedimentation. This process is variable depending on the sediment load of the river, the residence time of the water, the reservoir configuration, watershed management, etc. Sites/options with characteristics that minimise this process should thus be prioritised.	A rubber weir for automatic sediment flushing was built in a river in Japan, and the mitigation measure has been shown to be successful. (Source: Annex III, ST1 report) The 300 MW Fortuna HPP in Panamá has a 10 km^2 reservoir surrounded by a 160 km^2 natural reserve, covering the upstream watershed. This limits erosion risks and sedimentation. (Source: Hydro-Québec)

17 See Vol. III: Appendices. *Appendix A: Glossary.*

RECOMMENDATION # 4

Improving Environmental Management of Hydropower Plants

Once a hydropower project has been selected, a significant number of environmental and social considerations must be addressed. Many hydropower projects around the world already "internalise" (or fully account for) such requirements, while many others do not.

Recommendation #4 proposes 13 guidelines to improve environmental practices for project construction and operation.

RECOMMENDATION # 4

Improving Environmental Management of Hydropower Plants

Project design and operation should be optimised by ensuring the proper management of environmental and social issues throughout the project cycle.

This recommendation is based on the premise that hydropower projects must be harmoniously integrated into their surroundings and communities.

Choosing the right site to build a hydropower project is the first step towards a good project. But once the site has been identified, the project may still have to undergo a series of design changes that take into account environmental and social concerns. Hydropower projects do have impacts, regardless of the selected site. On the basis of the "polluter-payer principle", these impacts must be properly mitigated or compensated for. Communities must also be fully informed and consulted regarding such matters and the multiple uses of available water resources must be considered.

It is thus important to invest the required resources to be able to manage the environmental and social issues throughout the project cycle. Responsibilities must be clearly identified at each step to ensure that commitments are fulfilled throughout the project life.

This fourth recommendation includes a series of guidelines to help decision-makers to optimise the design and operation of projects. These guidelines are presented below.

GUIDELINES FOR HYDROPOWER PLANT OPTIMISATION	P	C	O	R	D
Mitigate water quality problems Water residence time is one of the most significant environmental variables that affect water quality and related problems such as anoxia, etc. Other problems related to water residence time can also be observed in reservoirs and downstream, in particular waterborne diseases such as malaria. Project design and operation must take these aspects into consideration in order to minimise as much as possible negative effects on water quality.	●	●	●	●	●
Facilitate upstream and downstream fish passage for migratory species Aquatic fauna and fish in particular sometimes travel long distances to provide for their needs. Physical structures and especially dams constitute barriers to such migrations. The selection of the dam site (sites with thresholds or falls for example) and design of mitigation measures (fish ladders, elevators, etc.) must be examined carefully in order to minimise this type of impact.	●	●	●	●	●
Plan and carry out monitoring and environmental follow-up programs Such programs are essential components of any hydroelectric project. Certain residual impacts remain and must be addressed by specific monitoring or follow-up programs. A proper environmental follow-up program requires the collection of a time-series of data both before and after the implementation of the project. Monitoring represents an essential activity to ensure the application and effectiveness of mitigation measures. Project monitoring should be periodically verified by carrying out environmental audits.	●	●	●	●	●
Design and implement power plant flow rules that take into account the needs of communities and the environment both upstream and downstream of the project Operating rules for hydropower facilities are conceived in order to supply a specific energy service. However, these rules must also take into account impacts on fish and other species, as well as other needs and multiple uses of water such as irrigation, fishing, navigation, recreation, water supply, etc.	●	●	●	●	
Plan construction activities to minimise adverse effects during the critical phases of species' life cycles At certain phases of their life cycles, species are more sensitive to disturbances, for instance at the time of reproduction. In order to protect those critical phases and the habitats of concerned species, it is important to minimise activities that may compromise the survival of such populations.	●	●		●	●
If necessary, implement a reservoir logging program taking into account the various uses of the reservoir Although it is generally expensive, logging of selected areas of a future reservoir may be required for environmental, technical or economic reasons, such as the recovery of commercial wood. Logging may also generate considerable benefits for future reservoir navigation and fisheries. However, standing logs in a reservoir can also constitute good habitats for fish and benthic fauna. The logging program must therefore be adapted to the various uses of the reservoir.	●	●	●		

LEGEND: **P**: Planning – **C**: Construction – **O**: Operation – **R**: Refurbishment – **D**: Decommissioning

GUIDELINES FOR HYDROPOWER PLANT OPTIMISATION	P	C	O	R	D
Evaluate the effectiveness of mitigation measures The effectiveness of many mitigation measures is well known. However some measures, for a variety of reasons, may require a specific follow-up program. This is particularly the case for experimental measures for which there is little or no experience available from other projects.		●	●		●
Use the lessons learned from past hydropower projects in EAs carried out for new projects Lessons are not always learned. The experience gained in one project is not always integrated into EAs carried out for subsequent projects. This is true for proponents, governments and NGOs alike. A systematic review of lessons learned should help minimise the resources required for future studies and avoid past mistakes.	●				
Strengthen countermeasures against earthquakes in zones of strong seismicity Projects in zones of strong seismicity should be designed with appropriate criteria in order to reduce risks such as dam failure. It is also necessary to implement monitoring and contingency plans for downstream communities.	●			●	●
Plan measures to avoid or control reservoir sedimentation In certain river basins, sedimentation is an important issue because of the high sediment load carried by rivers. This problem should be correctly evaluated at the planning stage in order to design appropriate mitigation measures, such as river basin afforestation programs.	●		●	●	
Compensate the loss of biological production on a regional scale Hydropower projects modify existing habitats. Lakes, rivers and various humid and terrestrial habitats are replaced by the aquatic habitats of reservoirs. Although local losses cannot always be avoided, such losses can be compensated for on a river basin or regional scale, by protecting or managing similar habitats nearby.	●		●		
Consider human health and safety issues in any Environmental Management System (EMS) Hydropower projects may affect human health and safety. Environmental Management Systems should therefore address potential adverse health impacts such as water-related diseases (malaria or presence of heavy metals), and safety issues such as downstream water releases.			●		
Assess the environmental impact of decommissioning a power plant Decommissioning a hydropower plant may have significant environmental and social consequences. If decommissioning involves emptying a reservoir, there is a risk that a balanced and productive reservoir ecosystem will disappear, and that the human activities surrounding the reservoir will be significantly affected by its removal. Such impacts must be assessed prior to taking a decision.					●

RECOMMENDATION # 5

Sharing Benefits with Local Communities

Beyond the project planning and design process discussed above, an important issue associated with hydropower projects is that of ensuring social justice through the *fair distribution of project costs and benefits* among local communities, society at large, project proponents and governments. In several cases, local communities have incurred most of the social costs of hydropower projects (in the form of involuntary population displacement, for instance), whereas most of the benefits have gone to other external constituencies: agricultural concerns, industries, urban communities, national or regional power supply and distribution systems, etc.

RECOMMENDATION # 5

Sharing Benefits with Local Communities

Local communities should benefit from a project, both in the short term and in the long term.

This recommendation considers that local communities are key players in hydropower projects because they are most directly affected by a project. Proponents must seek community involvement and partnership throughout the project cycle. Community support is most effective and legitimate when it involves broad constituencies including government agencies, non-governmental organisations, academic institutions, and other members of civil society.

Moreover, early community involvement is preferable, since project design is less likely to undergo major changes to suit the biophysical and socio-economic environment at a latter stage of project planning. The development of short term as well as of long term community benefits must be a foremost project goal and the only way to achieve such a goal is through a participatory planning process.

Community benefits do not necessarily mean monetary benefits, or might not even have to constitute monetary benefits at all. Improved access, improved infrastructure, support for health and education programs, legal title to land, are all important benefits that may be derived from a hydropower project. What constitutes a benefit, however, must be defined by locally affected communities on the basis of a participatory process.

What is meant by "affected communities" may vary greatly from one project to another. At the minimum, this term refers to people and communities who lose their livelihood, or their property, or access to resources that are essential for their livelihood, due to reservoir impoundment, construction works or downstream water flow changes.

However, defining who is affected by a project is a difficult exercise: Who decides? To what extent is a community "affected"? Beyond the minimal definition proposed above, there are many people and communities who may be affected to a certain extent by a project, whether positively or not. There are no simple answers, except to say that establishing who is affected by a project is often a negotiated exercise that is carried out between those who legitimately believe they are negatively affected by a project and those who represent the project proponent and/or relevant public authorities.

The following guidelines ensure a fair allocation of project benefits, while limiting adverse consequences for locally affected communities. These guidelines are based upon the implementation of a participatory approach with local communities.

GUIDELINES REGARDING BENEFITS TO LOCAL PEOPLE	P	C	O	R
Inform and consult local communities at all stages of project planning and implementation Every project raises questions and in certain cases sharp disputes. Public consultation is required to address the concerns of affected stakeholders. Consultations must be carried out as early as possible in order to ensure that the project incorporates communities' needs. Study results must be presented on a regular basis, to ensure transparency.	●	●	●	●
Cooperate with social and economic development agencies Many measures to mitigate and compensate socioeconomic impacts are dependent upon regional and national policies and programs which come under the responsibility of government agencies. Project proponents must therefore cooperate with such agencies in order to assess potential impacts and design appropriate mitigation, enhancement and compensation measures. The main areas to consider are: multiple reservoir and river uses, regional economic development, land-use planning, education and training, land expropriation, transportation and public health.	●	●	●	●
Design and implement monetary transfer mechanisms to local and regional institutions A regular revenue stream from the power plant operations allows for the implementation of regional infrastructure development and land-use planning initiatives, including watershed management or reforestation. Examples of such transfer mechanisms are: a regional tax corresponding to a percentage of the power plant's income, establishment of trust funds for environmental and economic development, or an equity share of local institutions in the ownership of the power station. Such transfer mechanisms must also apply to other types of power generation, such as coal, gas, nuclear or windpower.	●	●	●	●
Optimise local and regional economic spin-offs The onset of a project in a given area represents a potential source of employment opportunities. Throughout the project's life cycle, it is advisable to optimise the use of local and regional resources so that local communities benefit from the project. However, the qualifications of local labour do not always correspond to proponents' needs. In such cases, it may be advisable to provide technical training in such fields as environmental or social monitoring, natural resource management, etc.	●	●	●	●

LEGEND:
P: Planning – **C**: Construction – **O**: Operation – **R**: Refurbishment

GUIDELINES REGARDING BENEFITS TO LOCAL PEOPLE	P	C	O	R
Facilitate the involvement of affected people in the design and implementation of mitigation, enhancement and compensation measures The purpose of mitigation measures is to effectively minimise impacts that are often borne by local communities. In order to select and implement measures correctly, the participation of the concerned communities should be promoted, given their particular knowledge of the area and of local needs.	●	●	●	●
Ensure that vulnerable social groups benefit from the project Hydropower projects sometimes affect the lives of vulnerable social or ethnic/religious minority groups. It must be ensured that less privileged social groups, and not just dominant social groups, benefit from the project.	●	●	●	●
Plan and implement resettlement and rehabilitation programs for communities that are displaced or otherwise affected by the project Even when the best alternative is selected, involuntary population displacement is sometimes inevitable. The impacts of such activities are very complex, involve many stakeholders and cannot be dealt with within a short time-frame. The objectives of resettlement and rehabilitation programs must be to ensure the short- and long-term improvement of local standards of living by designing and implementing appropriate development opportunities for both displaced and "host" communities.	●	●	●	
Plan and manage public health programs A new hydropower project often leads to socioeconomic changes that may affect public health. Changes in living standards, in the quality of access to water, in the incidence of waterborne diseases such as malaria, are examples of changes that must be addressed. Programmes must be designed to ensure that local public health conditions are enhanced by the project.	●	●	●	
Integrate local ecological knowledge into project planning Beyond the studies which are required for any project, local knowledge can also be a source of relevant and useful information. It is thus necessary to ensure that this type of knowledge is taken into consideration in project planning.	●			●
During the planning and design phases, show openness in resolving local problems which existed prior to the proposed project The announcement of a new project often triggers the public re-emergence of unsettled problems from the past. These issues are often linked to previous projects carried out many years earlier. This is particularly true in the case of the upgrading of existing installations. These problems should be addressed even if they might not be directly related to the new project, as the project might help solve past grievances.	●			●
Support reservoir fisheries and other community uses of the reservoir Hydroelectric installations often include a large reservoir. Reservoirs might sustain significant local fisheries or other uses and may even be the subject of specific enhancement measures in order to increase their potential. In several countries, this aspect can be quite important for the local economy. It is thus advisable to support this kind of initiative, within reasonable limits.			●	